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PERSONAL FLOTATION DEVICES RESEARCH. PHASE I.(U)

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PERSONAL FLOTATION DEVICES RESEARCH PHASE I

DEPARTMENT OF TRANSPORTATION ★ UNITED STATES OF AMERICA ★

JULY 1976

FINAL REPORT

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16. Abstract

An Accident Recovery Model (ARM) for recreational boating accidents is presented. Its development and application are described. The model is used to estimate the benefits of regulatory programs in four recovery problem areas. Methods and problems in benefit estimation are described and recommendations for further development of ARM are offered. An investigation of the causes of sudden and unexplained drownings is reported, including a review of the biomedical literature and an analysis of boating accident reports. Development of the Life-Saving Index (LSI) is described, and its application to the approval of personal flotation devices (PFDs) is discussed. Past mathematical modeling efforts related to PFD effectiveness are discussed. A pilot experiment is reported and alternative empirical methods for evaluating PFD effectiveness are presented. A large-scale observational study of PFD wear and accessibility, and a study of PFD-related attitudes and preferences are reported. A preliminary index of PFD wearability is formulated. Initial data on PFD quality control and reliability problems are presented. Procedures for evaluating PFD reliability are outlined. Functions which future PFD designs could fulfill and features of inflatable and hybrid devices are reviewed. Tests of two inflatables and three hybrid devices are reported.

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METRIC CONVERSION FACTORS

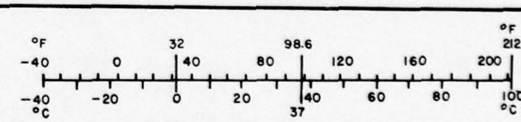
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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PERSONAL FLOTATION DEVICES RESEARCH — PHASE I

INTRODUCTORY SUMMARY

This report summarizes research conducted from July 1975 through July 1976 under Task 2 of USCG Contract DOT-CG-42333-A entitled Personal Flotation Devices Research. This report completes Phase I of the project.

Section 1.0 of the report describes the development of a technique for assessing the impact of Coast Guard regulatory and educational programs in reducing boating fatalities. This technique, called the Accident Recovery Model (ARM), shows the role of PFDs and their interrelationships with other elements of the recovery system (boat flotation, boaters' behavior, environmental conditions, etc.). ARM provides quantitative estimates of the number of lives saved by existing and proposed Coast Guard programs.

ARM also guides the PFD research effort by identifying problem areas in PFD functioning and by providing estimates of important parameters related to PFD effectiveness, wearability, and reliability. Preliminary results show that the following factors each save a significant number of lives annually and could produce even greater benefits if appropriate programs were instituted:

1) PFD use, including wearing a PFD
2) accessibility of PFDs so that they can be donned or held by accident victims after entering the water
3) the boater's decision to stay with the boat after entering the water
4) boats which happen to float level after being swamped or capsized, and level flotation boats.

Insufficient data was available to assess the effects of prolonged immersion in cold water (hypothermia) and the effect of PFD wear in retarding hypothermia. Methods and problems in estimating benefits are also discussed. Recommendations concerning the further development of ARM are offered.

The present work and previous research show that most deaths in boating accidents occur soon after the victim enters the water. Section 2.0 summarizes an investigation of these "sudden" drownings. An analysis of boating accident reports and a review of the biomedical literature were conducted to identify the circumstances surrounding and physiological causes for sudden and unexplained drownings. The results suggest that stress, alcohol, cardiac insufficiency, and reactions to sudden cooling all play a role. Methods for acquiring in-depth information on drowning and near-drowning victims are described. Additional physiological syndromes which may contribute to drownings will be investigated in Phase II of the project.

A major part of the present project is the development of a flexible regulatory tool for the evaluation and approval of diverse PFDs. Existing approval procedures help to insure that Coast Guard approved PFDs are effective and reliable, but do not address the problem of PFD use. The present study and previous research show that few boaters wear PFDs or even keep them accessible. Section 3.0 describes the development of a Life-Saving Index (LSI), a measure of the overall life-saving capability of a PFD. The LSI reflects the wearability and accessibility of the PFD as well as its effectiveness and reliability. The application of the LSI to the evaluation and approval of PFDs is discussed.

Sections 4.0, 5.0 and 6.0 report on the development of the component parameters or measures which make up the LSI. Methods are described for evaluating the effectiveness, wearability, accessibility, and reliability of both existing and future PFDs. These methods are the foundation for future recommended PFD approval procedures.

The physical effectiveness of a PFD (Section 4.0) is the probability that it keeps the wearer afloat in a position which permits continuous breathing. Previous research attempted to mathematically model the buoyancy characteristics of an unconscious human body and PFD. This approach failed to generate useful predictions. Wyle studied the problem areas in the human buoyancy model and investigated the effect of less restrictive assumptions. The mathematical model was finally abandoned in favor of a broader, empirical approach. The results of a pilot study are reported which considers effectiveness when the PFD is held and donned in the water as well as when worn. The results of the study show, among other things, that:

- Type II devices generally fail to turn the wearer from a face-in-the-water position to the head-back position.
- In some cases, Type III devices allow the wearer to turn from a head-back to a face-in-the-water position.
- Type IV devices were the most effective of those tested in keeping or turning subjects to a head-back position. However, they allow the wearer's head to fall backward, reducing their effectiveness.
- Type II and III devices almost always allow the wearer to turn to a face-in-the-water position when he or she adopts a huddled position similar to that recommended for protection against hypothermia.
- The Type IV buoyant cushion is the most difficult of the devices tested for the user to hold onto in the water.

Alternate methods for evaluating PFD effectiveness in the approval process are discussed.

The most serious problem with currently approved PFDs is that they are typically not worn and often not kept accessible. Regardless of their effectiveness and reliability, they therefore cannot contribute to the boating accident victim's survival. Section 5.0 reports the results of a study in which nearly 2500 boaters and 1000 boats were observed to assess PFD wear and accessibility. In addition, a pilot study is reported which measured PFD-related attitudes and preferences in the boating environment. The results show, among other things, that only 7.1% of the boating population routinely wears PFDs and that PFD appearance and the boater's "image" while wearing a PFD are the two strongest determinants of PFD wearability.

Section 6.0 reports preliminary research on PFD reliability and effective PFD life. Initial testing was conducted to evaluate current reliability test methods. Quality control in PFD manufacturing was identified as a major problem area. Initial data on PFD reliability are presented. Procedures for evaluating PFD reliability as a part of the approval process were developed.

The last section of the report (Section 7.0) describes the investigation of alternative PFD designs. The purpose of this section is to anticipate future industry development of PFDs in order to assure the continuing validity and usefulness of the LSI. Inflatable and hybrid PFDs and foreign PFD standards were reviewed to identify alternative design concepts. Two foreign-made inflatable devices and three Wyle-fabricated hybrid devices were tested for effectiveness and wearability. Inputs from ARM, the physical effectiveness, wearability, and reliability portions of the project were used to define criteria for test devices to be used in subsequent phases of the PFD research program. These devices will be used to evaluate the applicability of the LSI to new, innovative PFD designs.

1.0 ACCIDENT RECOVERY MODEL

1.1 INTRODUCTION

Research sponsored by the U. S. Coast Guard has examined a variety of problems related to accident prevention and recovery in recreational boating. For example, extensive investigations have been made concerning collisions, fires and explosions, flotation, boat stability, and the use and functioning of personal flotation devices (PFDs).

These investigations have revealed some of the more subtle problems and relationships involved in accident recovery and prevention. It has become increasingly clear that the occurrence of an accident, and recovery or fatality after an accident, are the result of a complex system of events and conditions. Some of the elements in the system are physical; others are psychological, physiological, economic, or social. For example, the factors which determine whether an accident results in recovery or a fatality can be categorized as follows:

- Accident dynamics, i.e., the type of accident, how quickly it occurs, etc.
- Physiological state of the victims, i.e., the presence of injury, shock, etc., obviously have a great bearing on the probability of recovery.
- Behavior of the victims, e.g., use or non-use of PFDs,
- Environment, e.g., water temperature, water conditions.
- Rescue facilities - there are a variety of possible modes of rescue, including self rescue, rescue by another boater on the scene, or rescue by the Coast Guard or other agency.
- Equipment - includes types of PFDs available, signalling devices, etc.

The recognition of the complexity of the factors determining accident occurrence and recovery or fatality has lead to a desire for better understanding of these systems. It has occurred to workers in this area that there may be effective ways of reducing accidents or promoting more favorable outcomes which have gone unrecognized. There is also a growing realization that actions which superficially would be expected to produce benefits could have unexpected and

undesirable ramifications. For example, improving the stability of small boats could result in a tendency for boaters to use them under conditions they would have otherwise avoided, thus possibly increasing the probability of an accident.

The present paper summarizes the first phase of an effort to describe those events and conditions which lead to recovery or fatality in recreational boating accidents. The preliminary work has taken the form of an Accident Recovery Model (ARM). This model describes the functioning and interrelationships of the elements of the accident recovery system. Some of these elements include: PFDs, boat flotation, rescue facilities, signalling devices, boaters' behavior, injury and other physiological conditions, and emergency treatment.

ARM is used to generate quantitative estimates of the benefits associated with proposed or existing regulatory or educational programs. For example, ARM can help to provide answers to the following questions:

1) Would it be beneficial to modify PFD design in the direction of greater "wearability" (e.g. comfort, attractiveness, etc.) even if this dictates a decrease in their physical effectiveness?

2) Would increased accessibility of PFDs help to compensate for the low rate of PFD wear?

3) Should PFDs provide greater protection against hypothermia?

4) Should PFDs be designed so that they are easy to don after the victim is in the water?

5) How might education increase recovery? For example, is the maxim "stay with your boat" always the best course of action?

6) How will improved boat flotation affect the role of PFDs in accident recovery?

During the formulation of ARM, three general methodological principles or objectives emerged. These three principles gave direction to the development of the model and helped to insure that the final product was useful.

The first of these principles was that the model must be empirical. It is based upon documented cases of recovery or fatality in recreational boating accidents rather than assumption or expert opinion. By building the model on an empirical base, one can have greater confidence that the result is a valid representation of the way recoveries and fatalities occur. ARM involves relatively few assumptions. Furthermore, these assumptions were checked and modified as needed as the additional data was gathered. ARM changed and grew to fit the data. In fact, ARM can be regarded as a structured summary of boating accident recovery data.

A second principle was that ARM must summarize the common elements in accident recovery while at the same time not sacrificing important relationships. In any type of modeling or analysis problem, there is a trade-off between summarization and representing detail. At one extreme, the average number of fatalities per accident could be regarded as a model. Obviously, this method sacrifices too much detail for an overall summary. The other extreme would be a detailed account of each of the accidents which occurred, say in 1974. This alternative doesn't sacrifice any details, but fails to point out commonalities among accident recoveries or fatalities. The model was developed in such a way as to capture important relatioships among elements of the accident recovery system that are common to many accidents.

The third criterion for ARM was that it must be in a form which is useable by the Coast Guard. This means that events or conditions which the Coast Guard can control by regulation, standards, or education must appear as elements of the model. This criterion also implies that the model must make use of existing accident data, even though such data is often incomplete and not representative of the population of boating accidents to be modeled. The problem of an unrepresentative data base is discussed later in this report and some tentative solutions are reported.

1.2 METHOD

1.2.1 Development and Preliminary Testing

This section reviews the various types of models and conceptual structures considered during the development of ARM.

Work on the accident recovery problem began with the consideration of the many factors which could affect the probability of recovery of a victim of a boating accident. The term "victim" refers to anyone involved in the accident regardless of whether the person survived or died. The first step was the compilation of a structured list of such factors. This list considered three general categories of variables: (a) Environment, (b) Behavior and condition of the victims, and (c) Equipment. The latter two categories were further subdivided into variables which were pre-existing or measurable well before the accident, and short-term factors which are measurable only at the time of the accident or afterward. The original list appears below:

I. Environment

- a) light conditions
- b) water temperature
- c) water conditions
- d) air temperature and wind velocity
- e) visibility (fog, cloudiness)
- f) location (type of body of water, distance from shore)
- g) rescue facilities

II. Behavior and Condition of the Victim

- a) Pre-existing factors
  - i) Prior knowledge experience, and attitudes
  - ii) Physical condition
  - iii) Susceptibility to stress
  - iv) Relationships among victims
  - v) Swimming ability
- b) Short-term factors
  - i) Condition of the victim (e.g., shock, injury)
  - ii) Fatigue, exposure
  - iii) Blood alcohol level

iv) Signalling behavior
v) Survival behaviors (e.g., using a PFD, staying with the boat, adopting a position which reduces heat loss, caring for other victims, etc.)

III. Equipment

a) Pre-existing factors

i) Flotation characteristics of boat
ii) Type and number and visibility of PFDs
iii) Visibility of craft after the accident (e.g., hull color)
iv) Signalling equipment

b) Short-term factors

i) Post-accident configuration of boat (e.g., capsized, sunk, mobile, immobile, etc.)
ii) Accessibility and condition of PFDs after accident
iii) Accessibility and condition of signalling devices after accident

The first type of model considered for ARM was a large contingency table or matrix of conditional probabilities. The frequencies or probabilities in the matrix would be determined by reviewing a sample of accidents, each of which would contribute information on a number of factors, such as those listed above. These factors would define an n-dimensional matrix. The matrix would allow one to determine the interrelationships among factors. Also, the probability of recovery for a given value on a factor (or combination of values on several factors) could be determined by collapsing this multi-dimensional matrix across other factors. The results could be used to identify important safety problem areas and interrelationships and estimate the benefit of alternative solutions.

Although the conditional probability matrix could summarize all the available factors related to accident recovery, the stochastic and time-dependent aspects of the accident recovery process would be lost. The next step in the development of ARM therefore involved the use of fault trees and event trees which attempted to represent the interdependencies between events over time.

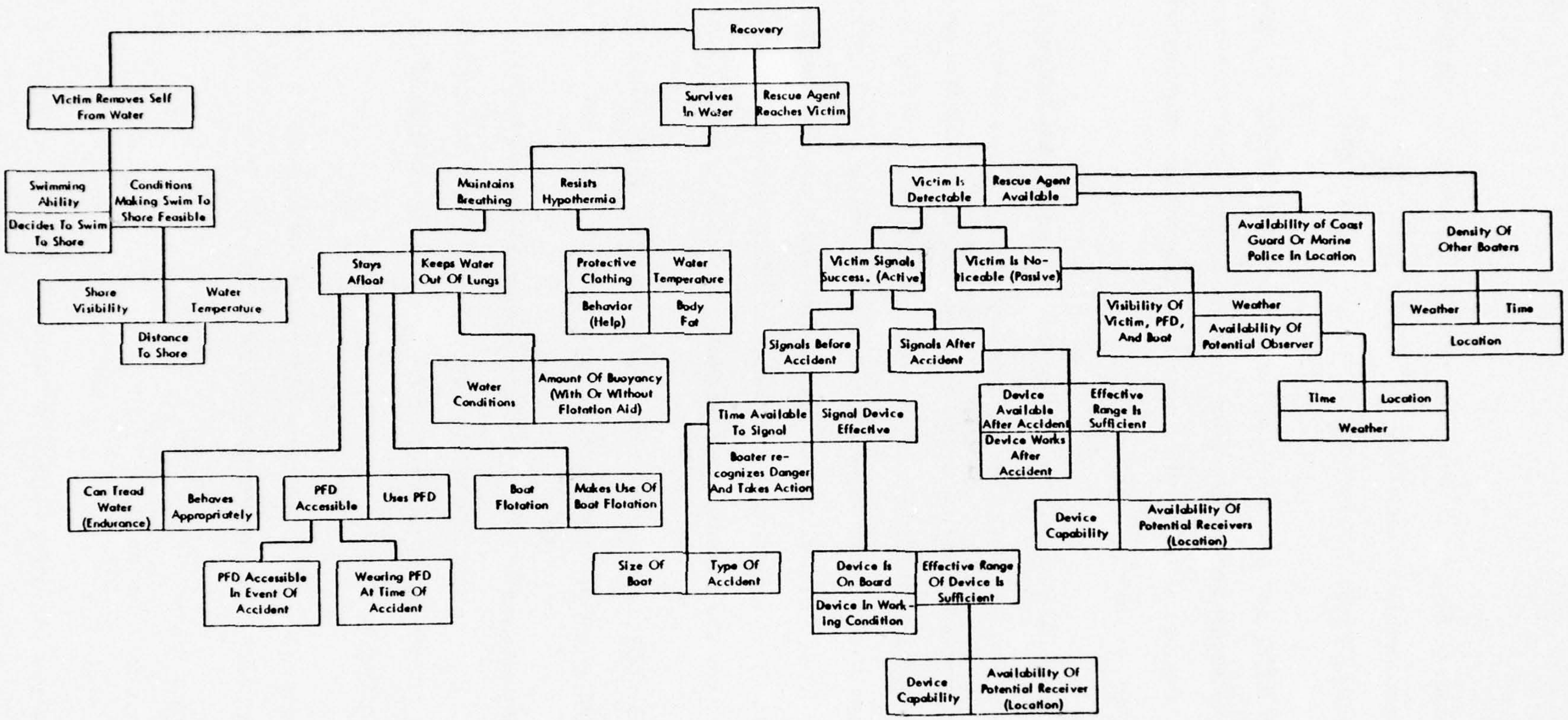
It is clear that accident recovery can be regarded as a time-dependent probabilistic process. In order to be recovered, the victim must survive for some period of time and a rescue team must reach him within that survival time. One can express the probability of recovery as follows:

$$P(\text{recovery}) = \int_{t=0}^{\infty} P \begin{Bmatrix} \text{victim is} \\ \text{surviving} \\ \text{at time } t \end{Bmatrix} \quad P \begin{Bmatrix} \text{first rescue} \\ \text{team reaches} \\ \text{victim at time } t \end{Bmatrix} \quad dt$$

In order to use this equation, one must determine how the probability of survival and the probability of rescue vary over time. Unfortunately, both probabilities depend on a multitude of factors, such as those appearing in the list above. The problem is complex, since the factors may not be statistically independent or mutually exclusive. For example, availability of PFDs may be strongly related to recovery in some types of accidents but of no importance in others. The problem is to specify which factors are important, under what conditions, and how these factors and conditions are related.

The first attempt at modelling recovery as a probabilistic process took the form of a fault tree (see Figure 1-1). This first version of the model (ARM_1) shows the factors and conditions which at the time seemed most strongly related to recovery. The diagram also shows how the individual events or conditions are related in determining recovery or fatality. Some events, such as "survives in water" depend jointly on other events, such as "maintains breathing" and "resists hypothermia." Where an event higher in the tree depends on the joint occurrence of events lower in the tree, the connecting line starts from the junction of the boxes surrounding the lower events.

In cases where two lines leaving a box go to lower boxes, the probability of a higher event depends on <u>either</u> of two subordinate events happening. For example, "PFD accessible after accident" could come about either because the victim was "wearing PFD at time of accident," or had a "PFD accessible in event of accident."



Note: Each box represents an event. Connected boxes designate joint events. Boxes which feed in parallel to the next highest level represent the union of events (either or both events determine the next highest event).

FIGURE 1-1. ARM$_1$

One of the major advantages of ARM_1 was that it showed how the unknown, the probability of recovery, is related to measureable probabilities. The lowest level elements in Figure 1-1 all represent measureable probabilities, such as the probability that a victim can tread water.

The main disadvantage of ARM_1 was that the factors and their interrelationships were determined logically or on the basis of expert knowledge of the recovery process rather than empirically. Because of this property, the user of ARM_1 might overlook important but unknown relationships between factors influencing recovery.

The next version of the model (ARM_2) took the form of a decision tree (see Figure 1-2). This model shows various conditions or events believed to be important in the recovery process. ARM_2 acts both as a data processing device and as a summary device. Accident reports are processed or coded from the top to the bottom of the tree. A tally mark is added alongside the appropriate node every time a person involved in an accident experiences the corresponding combination of conditions. After a large number of cases are processed, summary statistics can be computed for each node, including the number of accident victims who experience that combination of conditions and the probability of recovery for those victims.

The letters F_1 - F_8 in the model represent time dependent functions which relate the probability of recovery to factors such as water temperature, water conditions, and time until rescue.

As accident reports were processed in ARM_2, it became apparent that many factors could be added. This led to the third major version of the model (ARM_3) shown in Figures 1-3a and -3b. (Note: R means recovery and F means fatality). ARM_3 was the first version of the model to be subjected to formal testing.

In order to determine areas in which the Accident Recovery Model required further refinement and to test its usefulness, ARM_3 was used to model accidents of four types:

- Collisions and Groundings
- Capsizings and Swampings
- Explosions and Fires
- Miscellaneous including Falls Overboard, Persons Struck by Boats, etc.

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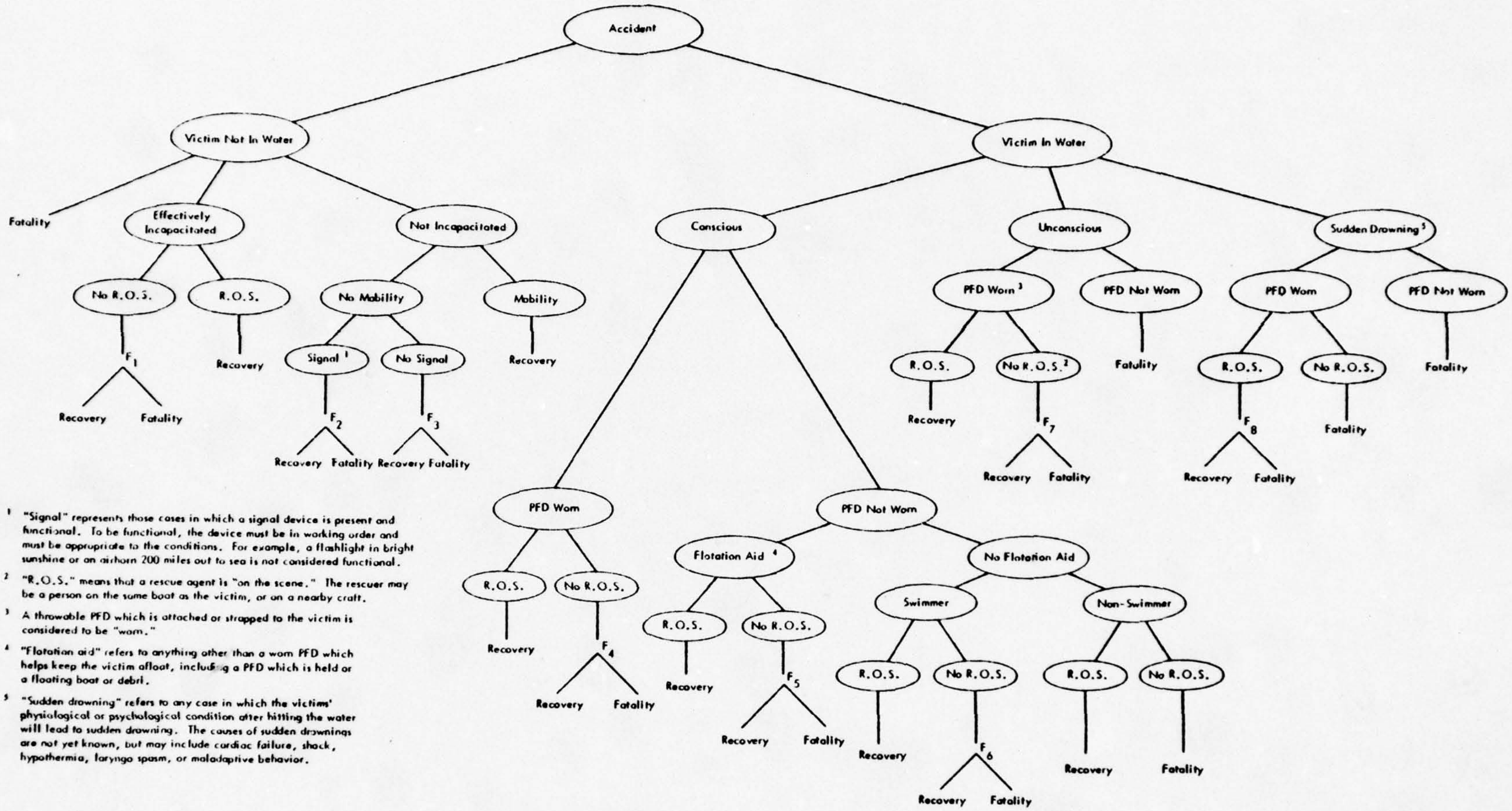
ACCIDENT RECOVERY MODEL



1 "Signal" represents those cases in which a signal device is present and functional. To be functional, the device must be in working order and must be appropriate to the conditions. For example, a flashlight in bright sunshine or an airhorn 200 miles out to sea is not considered functional.

2 "R.O.S." means that a rescue agent is "on the scene." The rescuer may be a person on the same boat as the victim, or on a nearby craft.

3 A throwable PFD which is attached or strapped to the victim is considered to be "worn."

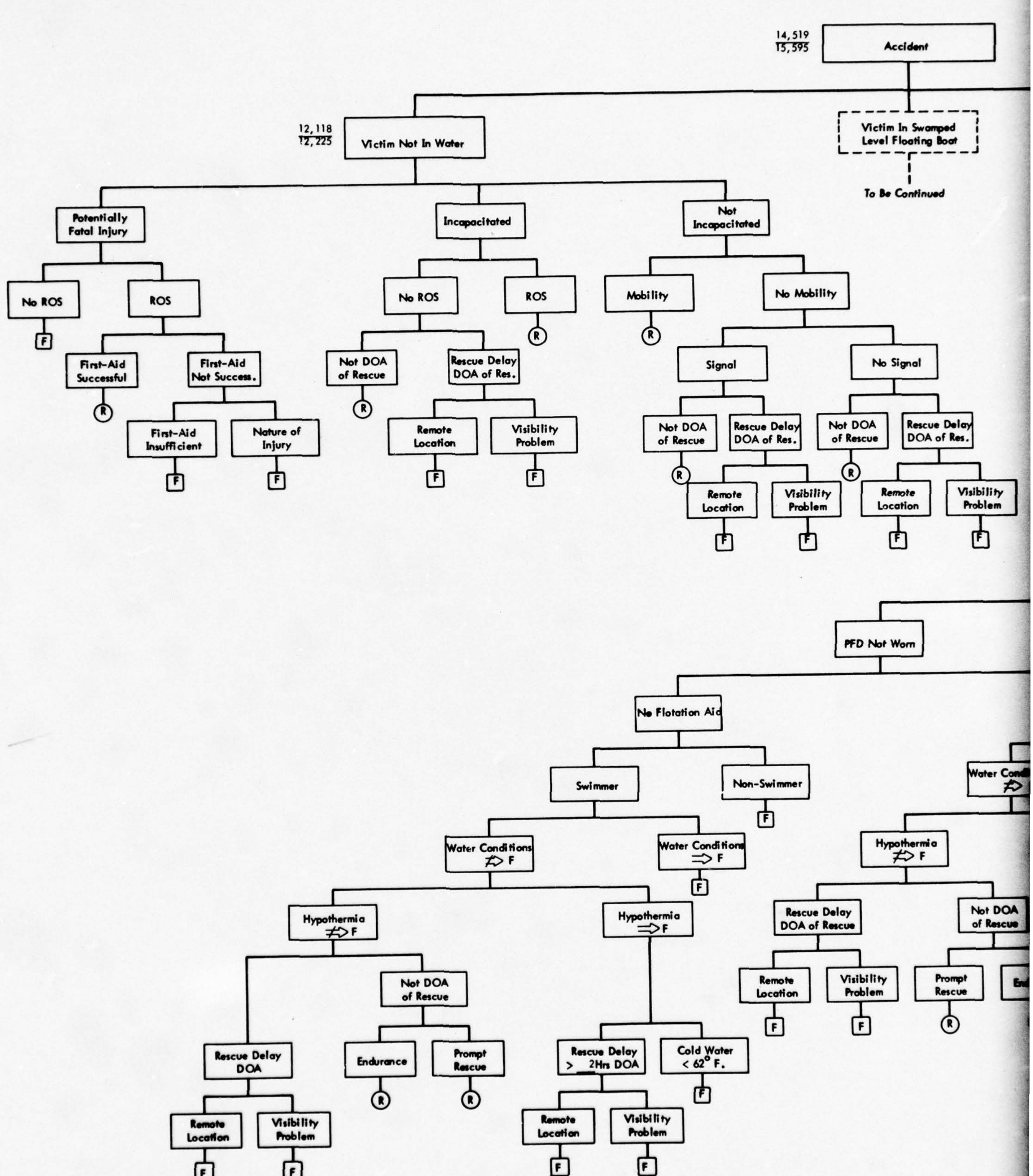
4 "Flotation aid" refers to anything other than a worn PFD which helps keep the victim afloat, including a PFD which is held or a floating boat or debri.

5 "Sudden drowning" refers to any case in which the victims' physiological or psychological condition after hitting the water will lead to sudden drowning. The causes of sudden drownings are not yet known, but may include cardiac failure, shock, hypothermia, laryngo spasm, or maladaptive behavior.

FIGURE 1-2. ARM_2

19
20X

ACCIDENT RECOVERY MODEL EVENT TREE



NOTES:

a) "Signal" represents those cases in which a signal device is present and functional. To be functional, the device must be in working order and must be appropriate to the conditions. For example, a flashlight in bright sunshine or an airhorn 200 miles out to sea is not considered functional.

b) "ROS" means that a rescue agent is "on the scene." The rescuer may be a person on the same boat as the victim, or on a nearby craft.

c) A throwable PFD which is attached or strapped to the victim is considered to be "worn."

d) "Flotation aid" refers to anything other than a worn PFD which helps keep the victim afloat, including a PFD which is held or a floating boat or debris.

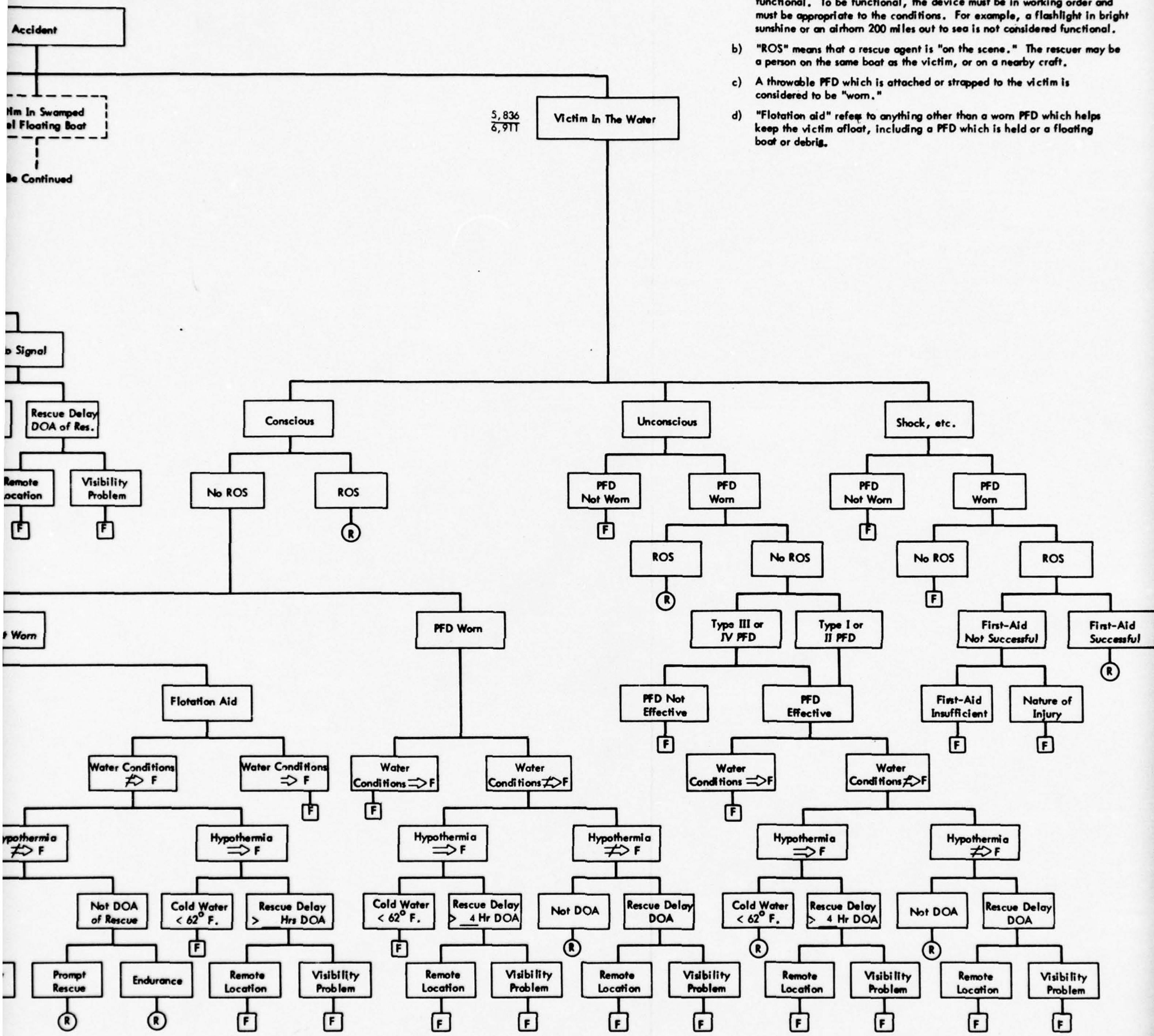


FIGURE 1-3a. ARM_3 AND PROJECTED RATIO OF VICTIMS RECOVERED TO TOTAL VICTIMS FOR THE TOPMOST NODES

DATA SHEET FOR ACCIDENT RECOVERY MODEL

Accident Number: ________

1. Specify type of accident: ______________________________

2. Specify time to recovery or fatality, if known: ______________________________

3. Specify type of injury ______________________________

4. Type of mobility ______________________________

5. Type of signal ______________________________

6. Specify whether rescuer was POB victim's boat ______ , Other craft ________

7a. Amount of time in water to recovery or fatality, if known ______________

7b. Water temperature, if known ______________________

7c. Water conditions, if known ______________________________

8. Specify other relevant physiological or behavioral conditions, if known: ________

____

9. Type of PFD worn ______________________________

10. Specify type of flotation aid ______________________________

Answer the following questions:

Was victim conscious?	Yes	No	
Was victim injured?	Yes	No	
Was there an R.O.S.?	Yes	No	
PFD held?	Yes	No	N/A
PFD worn?	Yes	No	N/A
Swimmer?	Yes	No	N/A
Boat has flotation?	Yes	No	N/A
Held onto boat or other flotation?	Yes	No	N/A
Water conditions	Calm	Rough	
Water temperature	$T \leq 62^\circ$	$62^\circ < T < 73^\circ$	$T \geq 73^\circ$ F.
Outcome	Recovery	Fatality	

FIGURE 1-3b. SUPPLEMENTARY DATA SHEET FOR ARM_3

A total of 129 accidents were coded using ARM_3.

Most of the accidents modeled were those for which Wyle in-depth accident investigation reports were available. As the Accident Recovery Model must be able to accept less detailed data, a number of Coast Guard Boating Accident Reports (BARs) were also modeled.

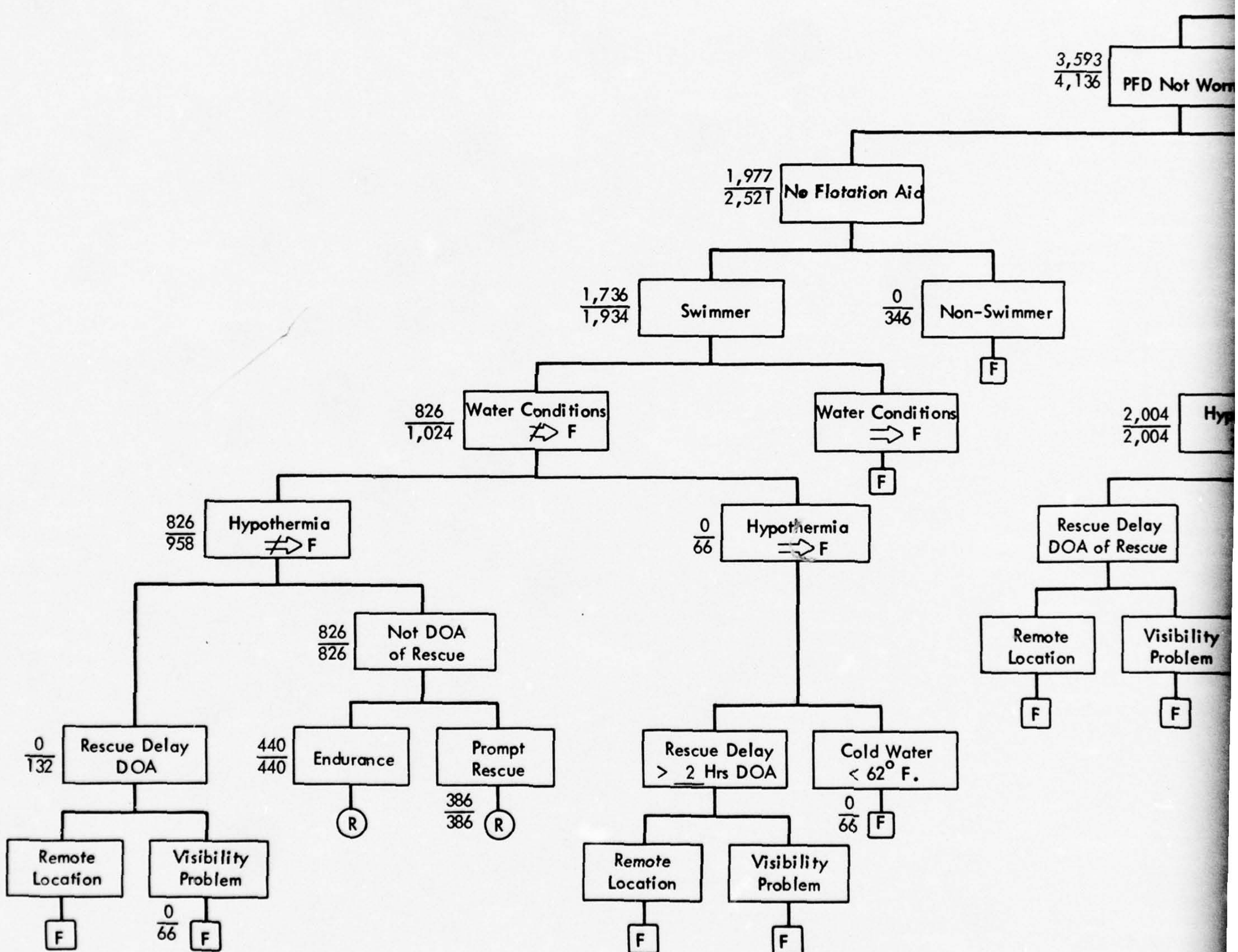
The modeling of sampled accidents served several purposes:

- Determine the model's ability to accommodate different accident types and scenarios
- Test the ability of the model to handle extremes in data availability, from highly detailed reports to quite sparse information
- Determine how well the coding of individual accidents can be replicated. Obviously, replicability or reliability in coding is necessary if the model is to validly represent the population of recreational boating accidents.
- Furnish numerical data (frequencies and probabilities) for use in testing benefit estimation methods.

Experience gained from the modeling of sampled accidents also resulted in modifications of ARM_3, such as expanding portions of the tree and modifying definitions and modeling techniques. These changes were incorporated in ARM_4.

The data obtained from the initial testing can be used to illustrate applications of ARM. Figure 1-4a illustrates projections for the entire boating accident population as reported in CG-357 based on the sample data for a portion of the ARM_3 decision tree. As the sample of accidents modeled was not random, the projected frequencies are not necessarily representative of the actual boating accident population. <u>These preliminary data were used only for purposes of illustration and model refinement.</u>

The ratio to the left of each node represents the number of accident victims rescued who passed through that node over the total number of victims passing through that node. For instance, at the node "PFD Not Worn," 4136 victims entered this node either from the path above or as the result of "changes of state." Of these 4136 victims, 3593 survived. In a few cases the recovery events for a victim were not adequately represented by the pathways in ARM_3, such as when a victim wearing a PFD removed it. In these cases the victim was considered to have "changed



3,593
4,136
PFD Not Worn
1,977
2,521
No Flotation Aid
1,736
1,934
Swimmer
0
346
Non-Swimmer
F
826
1,024
Water Conditions ⇏ F
Water Conditions ⇒ F
F
2,004
2,004
826
958
Hypothermia ⇏ F
0
66
Hypothermia ⇒ F
Rescue Delay DOA of Rescue
826
826
Not DOA of Rescue
Remote Location
Visibility Problem
F
F
0
132
Rescue Delay DOA
440
440
Endurance
Prompt Rescue
R
386
386
R
Rescue Delay > 2 Hrs DOA
Cold Water < 62° F.
0
66
F
Remote Location
Visibility Problem
0
66
F
F
Remote Location
Visibility Problem
F
F

2

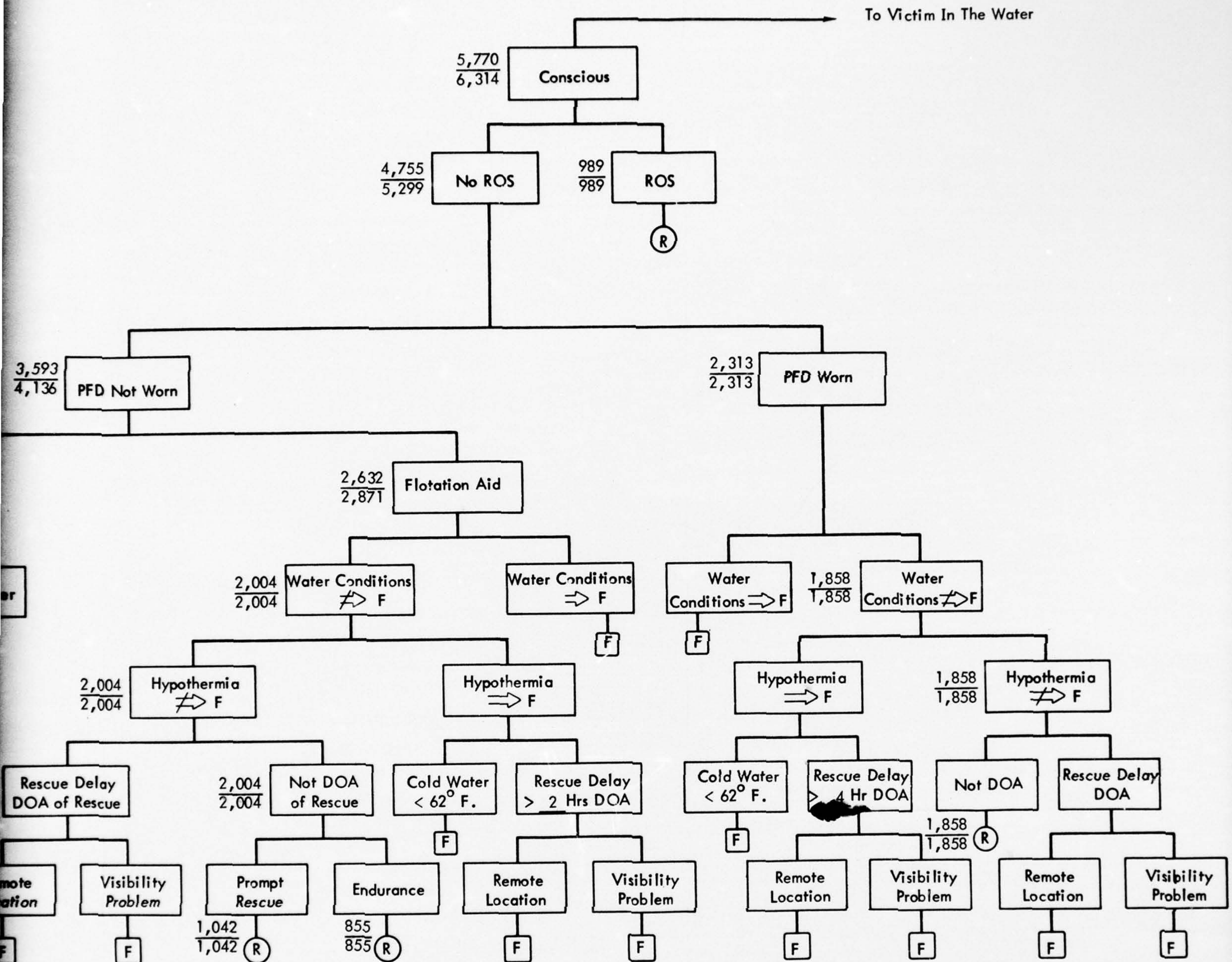


FIGURE 1-4a. PROJECTED RATIO OF VICTIMS RECOVERED TO TOTAL VICTIMS FOR A PORTION OF THE ARM_3 DECISION TREE

states" (or nodes) and was counted at both nodes. It should be noted that frequencies at some nodes do not sum to the frequencies at a higher, originating node because of changes of state involving these nodes or because of the inclusion of data at the higher node on accidents for which no further information was available to determine the choice of a lower node. Later versions of the Accident Recovery Model eliminated the change of state difficulty. Also, frequencies do not appear at those nodes for which the sampled data gave no information.

ARM_3 was also used to generate preliminary estimates of benefits for hypothetical Coast Guard programs in several areas. One of the simplest examples is shown in Figure 1-4b. The example estimates the benefits to be gained by increasing the use of flotation aids among accident victims who do not wear a PFD. This example ignores the possibility that other factors associated with using a flotation aid may distort the probabilities of recovery at either node. This problem is discussed later in this report.

1.2.2 Revision and Application

The model presented in this section is the result of considerable evolution and revision of previous work. Meetings with Coast Guard and Wyle personnel concerning previous versions pointed out several areas where the model could be expanded or revised. Further study of these suggested changes revealed that, in order to do a complete job, considerable expansion would be required. In fact, the expansion was so great as to make their incorporation into a single decision tree unwieldy. For this reason, separate decision trees covering various aspects of the recovery problem were constructed For example, decision trees were constructed to cover only distress notification and only PFD availability and use.

As in the previous versions of the model, the decision trees serve both as a description of factors and their interrelationships and as a data analysis device. Reports concerning each accident victim are used to trace a path from the top to the bottom of a tree. Frequencies with which particular paths are traversed can then be tabulated and weighted according to exposure data from other sources. Finally, the weighted frequencies can be used to estimate the benefit to be gained from certain regulatory actions or educational programs.

EXAMPLE: MAKING USE OF AVAILABLE FLOTATION

Suppose that through education 80% of those conscious victims not wearing a PFD remain with their floating boat, or hold onto a PFD or other flotation aid.

Present Situation:

No Flotation Aid	Flotation Aid
$\frac{1977}{2521}$ P(R)[1] = .79	$\frac{2632}{2871}$ P(R) = .92

Projected Recoveries = 1977 + 2632 = 4609

Predicted Situation:

No Flotation Aid	Flotation Aid
$\frac{852}{1078}$ P(R) = .79	$\frac{3969}{4314}$ P(R) = .92

Victims with flotation aid = .80 X Total Victims
= 4314

Projected Recoveries = .79 (1078) + .92 (4314) = 4820

Projected Additional Lives Saved Per Year = 4820 - 4609 = 211[2]

[1] P(R) = the estimated probability of recovery for a node.

[2] These numbers are presented for illustrative purposes only. They do not represent accurate benefit estimates.

FIGURE 1-4b. AN EXAMPLE OF PRELIMINARY BENEFIT ESTIMATION FOR PROGRAMS DESIGNED TO INCREASE THE NUMBER OF VICTIMS WHO "STAY WITH" THE BOAT AFTER AN ACCIDENT

Constructing separate decision trees for each portion of the recovery problem resulted in an important advantage over the previous model. In order to keep the model from becoming unwieldy, ARM_3 included only those factors on each path which could be expected to heavily influence the probability or recovery. For example, signalling appears under "Victim Not In The Water," but not under "Victim In The Water" in ARM_3. The revised ARM treats signalling, use of boat flotation, PFD use, etc., independently. Information relating to each and every portion of the recovery problem is available regardless of what path the victim may take on other dimensions.

Another important advantage obtained by treating each portion of the recovery problem independently is that the new version of ARM contains much more information than the earlier model. The earlier all-inclusive decision tree (Figure 1-3a) described 56 possible alternative pathways or combinations of conditions. The new ARM decision trees can represent a much larger number of combinations of conditions. Obviously, the large number of conditions represented increases the model's flexibility. In the new model, one can examine interrelationships which may have initially seemed unimportant, but later gained greater significance. For example, it may be of interest to know whether victims wearing PFDs are more likely to abandon their boat and swim for shore than victims not wearing a PFD. This is just one example of a large number of interrelationships which might be of interest.

ARM_4 consists of a coding sheet and decision trees which treat six different portions of the recovery problem. The model is shown in Figures 1-5 through 1-11. Each row on the coding sheet (Figure 1-5) summarizes the information for a single individual, or "victim," involved in a boating accident. After a sufficiently large number of victims are coded, the information can be punched on cards and processed by computer.

The numbers along the top of the coding form represent variable numbers (Figure 1-5). There are three types of variables. Variables numbered 1 - 7 contain file information which serves to locate the source in Wyle or Coast Guard files. Variables 8 - 23 provide miscellaneous recovery-related information and the information which will be needed to scale ARM data to reflect the population of boating accidents at large. The methods used to accomplish the

scaling are reviewed in the next section of this report. The last group of variables (24 - 40) contain the major recovery-related information. The values to be coded for variables numbered 24, 26, 28, 30, 33 and 36 are obtained from the accompanying decision trees.

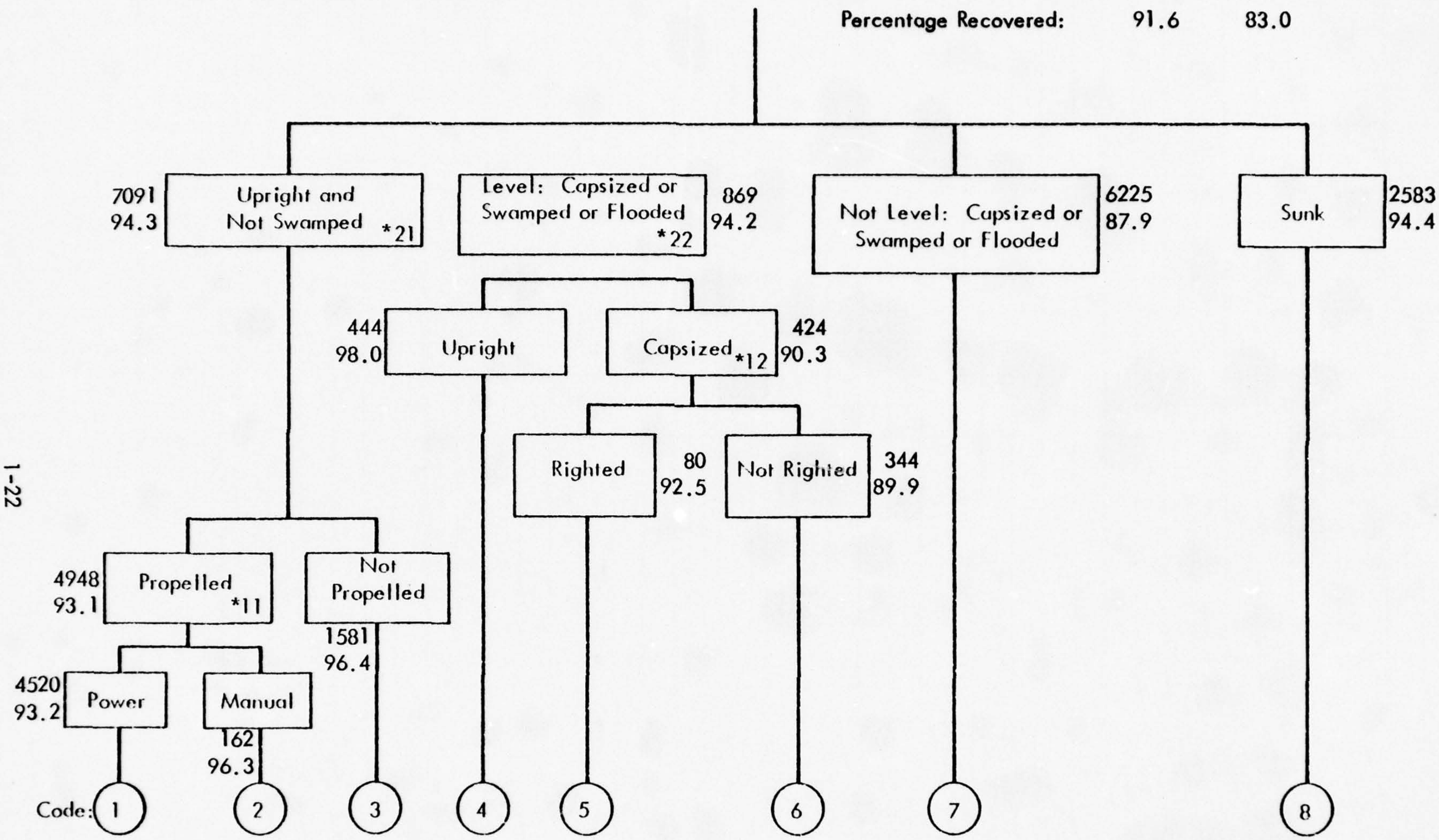
It should be noted that the conditions represented in each of the ARM_4 decision trees were not chosen arbitrarily. The combinations of conditions shown in each tree are (or should be interpreted as) mutually exclusive possibilities. In other words, only one set of conditions in a given decision tree can apply to any one victim. The main consequence of this property is that the coding sheet (Figure 1-5) can be made relatively compact without discarding important information.

The coding instructions and notes used with ARM_4 are shown in Appendix 1-A.

1	Wyle or BAF Number
2	Coded by
3	Verified by
4	ARM Coding Group
5	ARM Boat Number
6	ARM Victim Number
7	Reel Number
8	State
9	Month
10	Year
11	Time
12	Boat Length
13	Number P.O.B.
14	Number PFD's on board
15	Jurisdiction
16	Accident Type
17	Boat Type
18	Activity
19	Body of Water
20	Distance to Shore/Vessel
21	Assisting Party
22	Victim's Sex M=1 F=2
23	Age A=1 T=2 C=3
24	Final Boat Configuration
25	Level Flotation Boat? Y=1 N=2
26	Victim's Condition
27	Health
28	Behavior/Circumstances
29	Time In/With Boat
30	PFD Available/Use
31	Time Till PFD Donned/Removed
32	Sufficient PFD's on board? Y=1 N=2
33	PFD Type
34	PFD Malfunction? Y=1 N=2
35	Improper PFD Use? Y=1 N=2
36	Distress Notification
37	Water Temperature °F
38	Time In Water
39	Water Condition
40	Outcome R=1 F=2

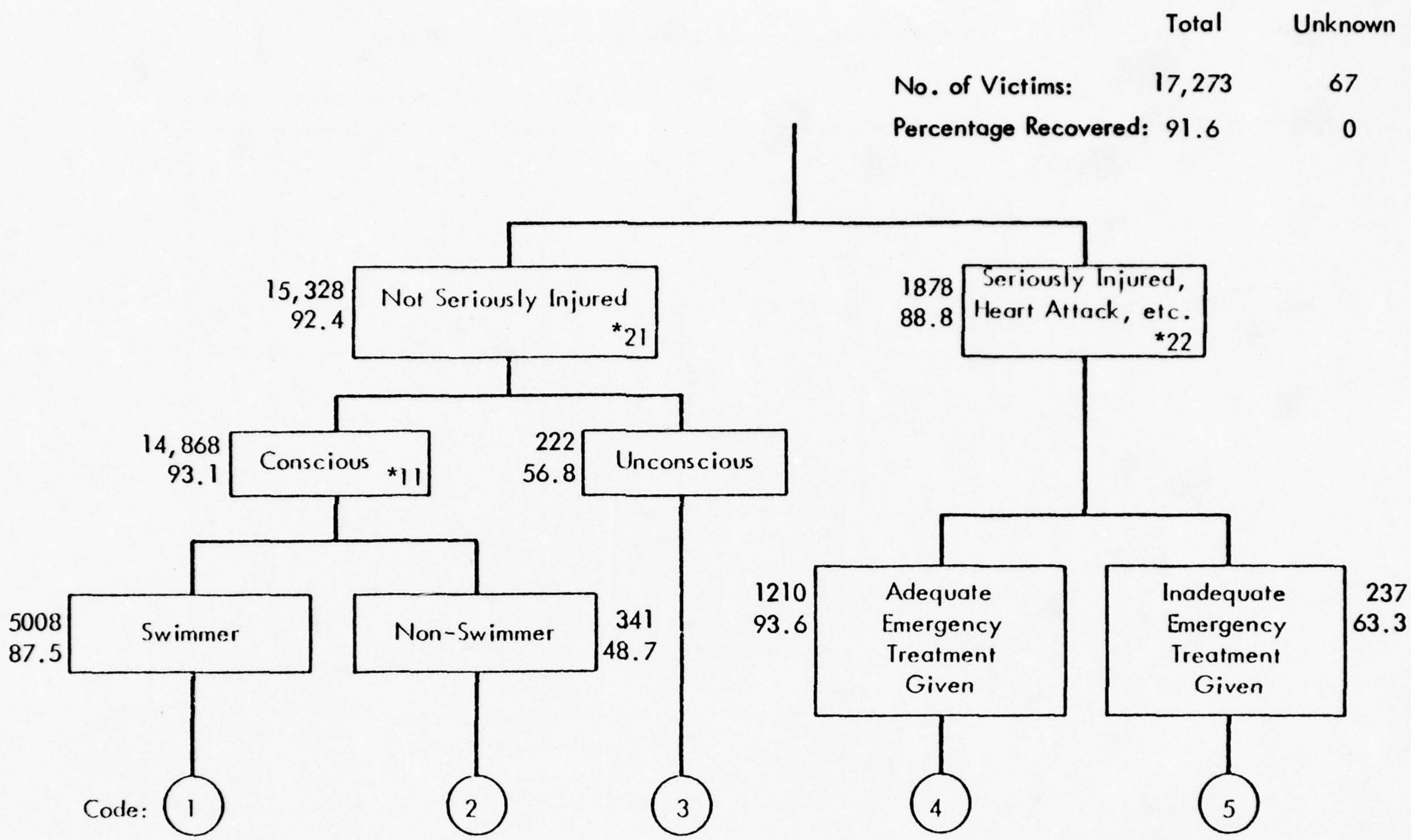
FIGURE 1-5. ARM_4 CODING SHEET

	Total	Unknown
No. of Victims:	17,273	505
Percentage Recovered:	91.6	83.0



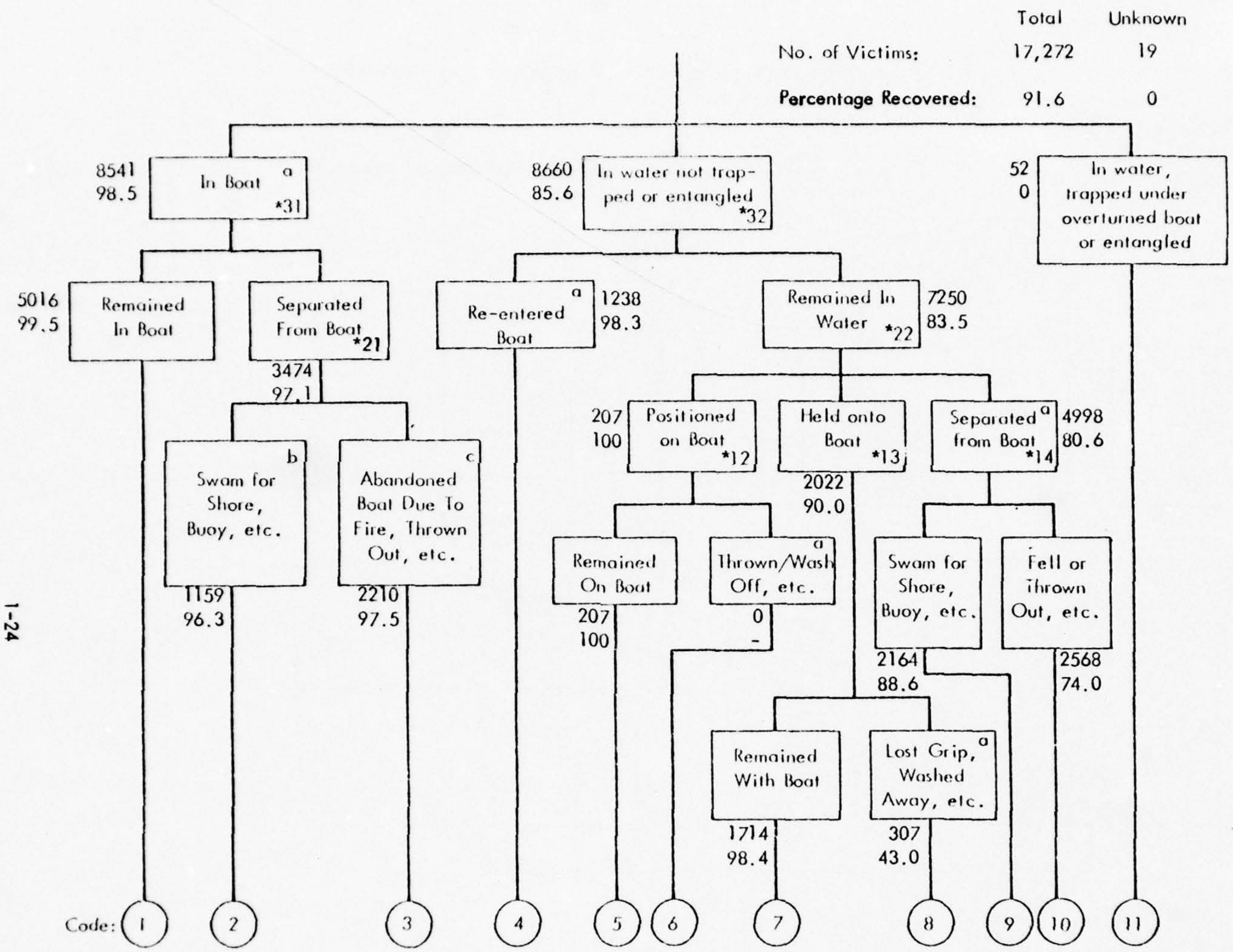
*Use these 2-digit codes when further information is not available.

FIGURE 1-6. ARM DECISION TREE FOR FINAL CONFIGURATION OF BOAT (VARIABLE 24)



*Use these 2-digit codes when further information is not available.

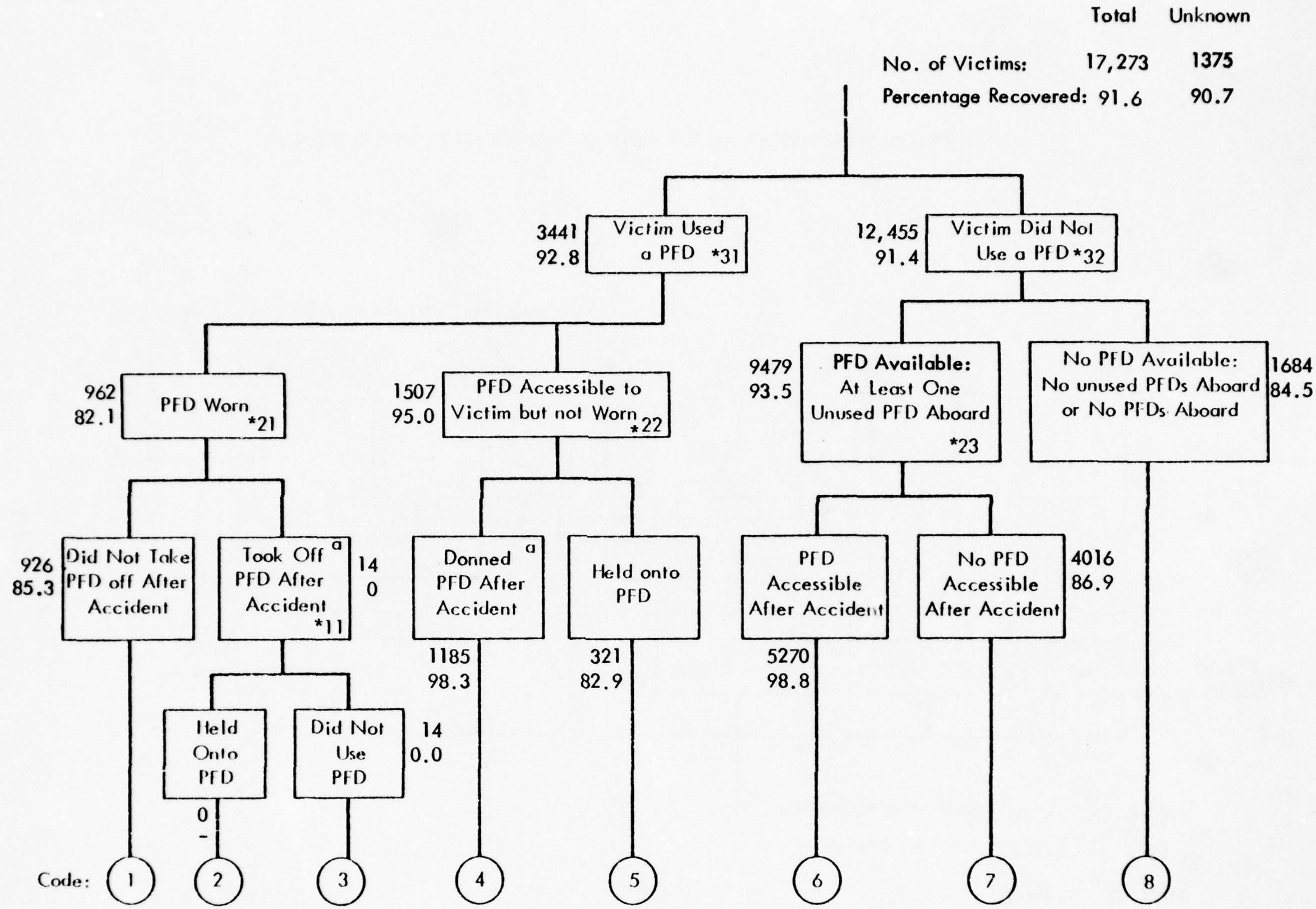
FIGURE 1-7. VICTIM'S CONDITION (VARIABLE 26)



a - Code time in or with boat after accident as variable 29. b - voluntarily left boat. c - involuntarily left boat.

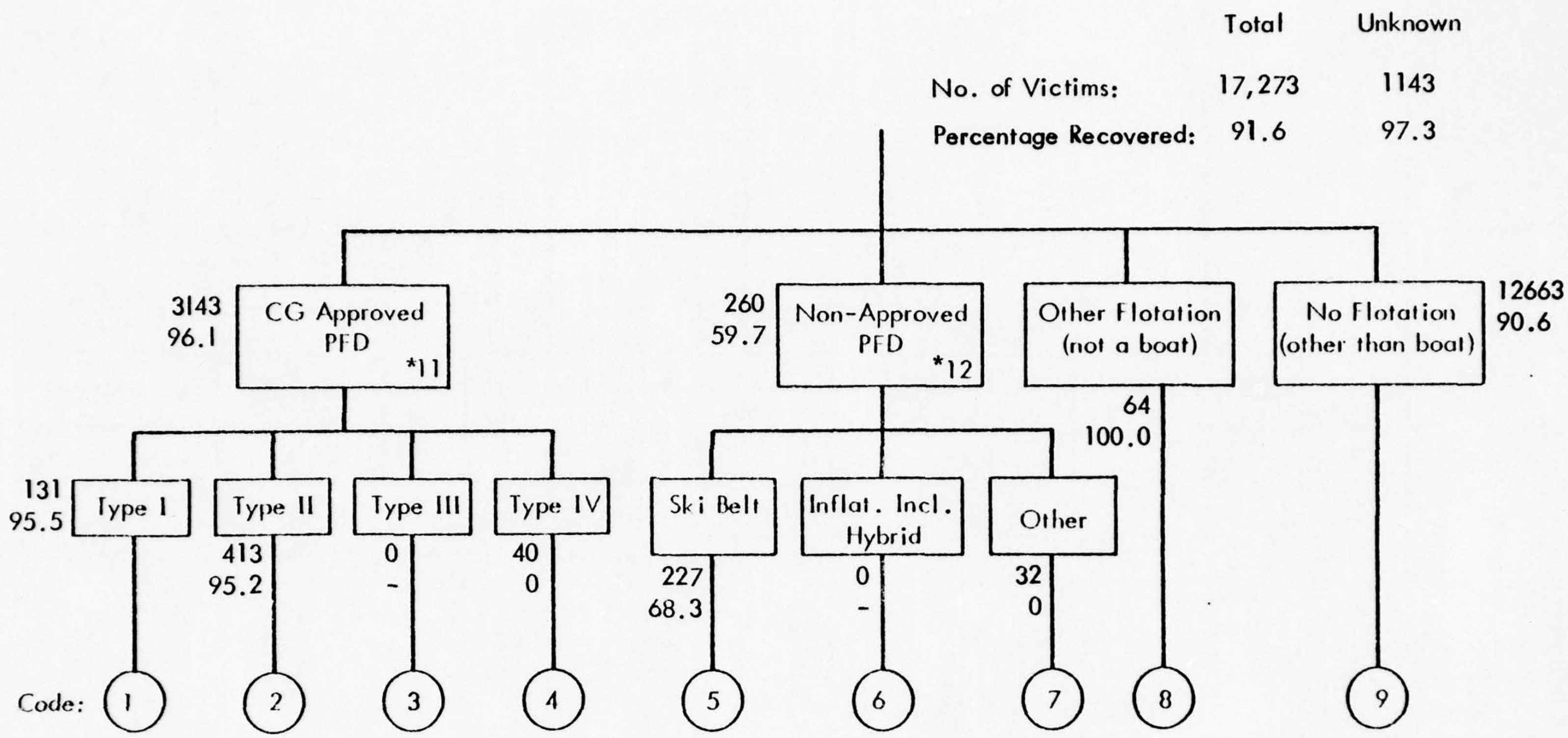
*Use these codes when further information is not available.

FIGURE 1-8. VICTIM'S BEHAVIOR AND CIRCUMSTANCES (VARIABLE 28)



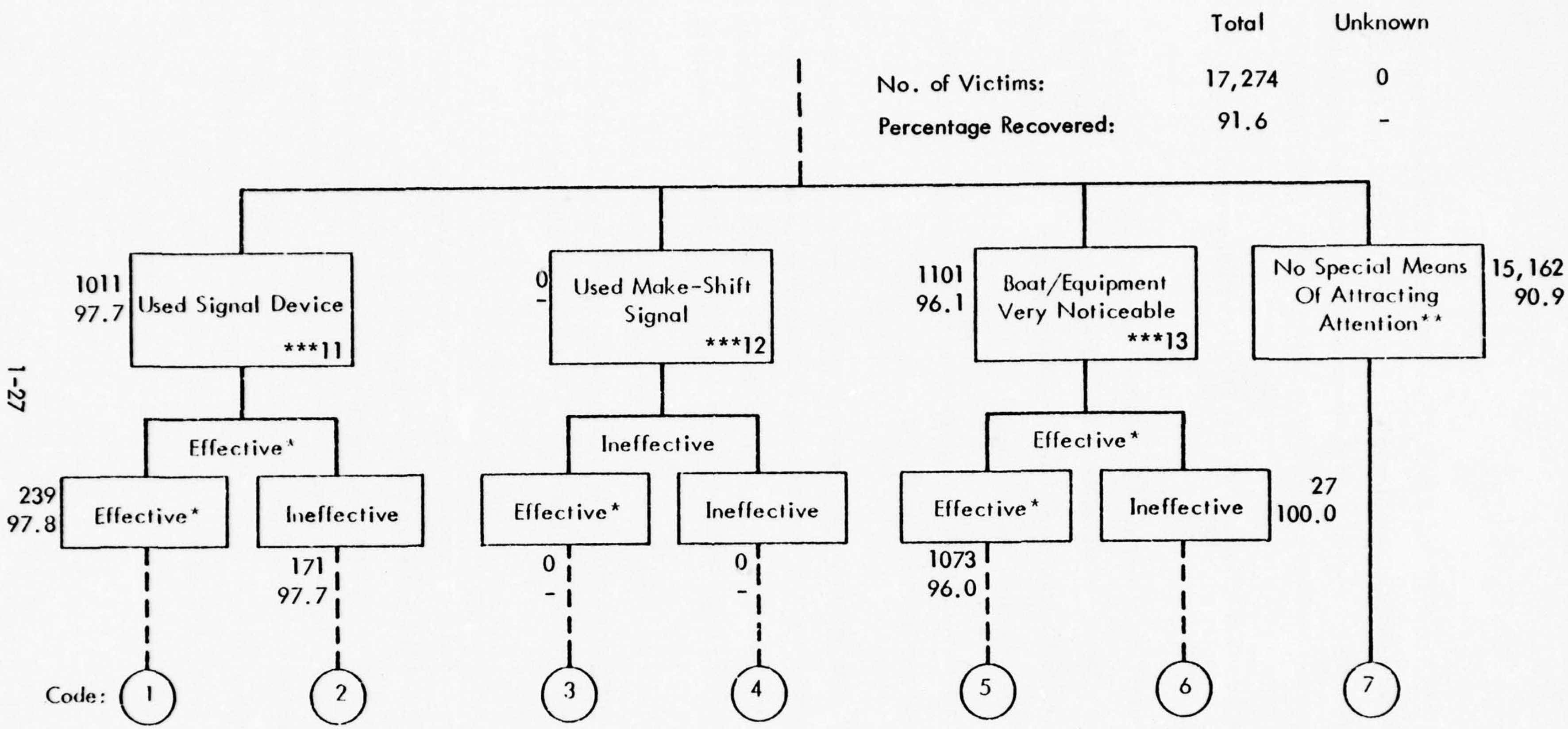
a - Code time until PFD was donned or taken off as variable 31.
*Use these codes when further information is not available.

FIGURE 1-9. PFD AVAILABILITY AND USE (VARIABLE 30)



*Use these codes when further information is not available.

FIGURE 1-10. TYPE OF PFD, IF ANY, USE BY VICTIM (VARIABLE 33)



* A signal is considered effective if anyone recognizes it as a sign of distress.

** Hand-waving, shouting, waving a piece of clothing or PFD should be coded "7."

*** Use these codes when further information is not available.

FIGURE 1-11. DISTRESS NOTIFICATION (VARIABLE 36)

In order to make the results of ARM as representative as possible and minimize later adjustments or weighting of the data, a stratified sampling plan was devised. The goal of this plan was to make the sample as representative as possible of the population of boating accidents described by the Coast Guard's yearly statistics as published in CG-357 (1973, 1974, 1975).

Stratification was carried out as follows. Two high priority variables were selected which satisfied the following criteria:

1) They were judged to have the most effect on accident recovery of those variables for which information is available in the data base (including BARs, Marine Inspection Officer [MIO] reports, state marine police reports, and Wyle in-depth investigations).

2) Data on the joint frequency distribution of accidents as a function of the variables was available in CG-357.

The variables selected were type of accident and boat type. Accident reports were selected for coding in ARM in such a way that the frequency distribution of the sample matched that of the population as closely as possible. In order to smooth out yearly fluctuations in the CG-357 statistics, the percentages for each of three years (1972 - 1974) were averaged.

In addition to the high priority variables discussed above, accident reports were sampled to match the population as nearly as possible as to geographic region and jurisdiction of the waters. The match of the sample to the population is quite good on both pairs of variables (see Tables 1-1 and 1-2).

Some additional sample statistics of interest are the type of accident reports used and the distribution by year. The ARM sample was made up of almost entirely BARs with attached MIO reports (98% of the accidents in the sample). The remainder were in-depth investigations conducted by Wyle. The distribution of sampled accidents by year in which the accident occurred is shown in Table 1-3. The selection of accident reports was conducted by proceeding through the file in a non-systematic fashion. Accident reports which would have been coded "unknown" on many ARM variables were not used. The coding for each victim in ARM was verified by a second coder and any discrepancies were resolved in conference. The ARM

TABLE 1-1 . PERCENTAGE OF TOTAL ACCIDENTS BY BOAT TYPE AND ACCIDENT TYPE ACCORDING TO CG-357 AND ARM SAMPLE

BOAT TYPE: ARM	BOAT TYPE: CG-357	Collisions and Groundings (ARM) / Grounding, Collision w/Another Vessel & w/Fixed Object, Striking Floating Object (CG-357)	Swamping, Flooding, Capsizing (ARM) / Capsizing, Flooding, Sinking (CG-357)	Fires and Explosions (ARM) / Fire or Explosion of Fuel; Other Fire or Explosion (CG-357)	Falls Overboard (ARM) / Falls Overboard (CG-357)	Struck by Boat or Propeller (ARM) / Struck by Boat or Propeller (CG-357)	Other (ARM) / Disappearance of Boat, Other Casualty to Vessel, Disappearance of Person, Falls Within Boat, Burns & Scalds, Crushing or Pinching, Other Personnel Casualties (CG-357)	Totals
Open Manual (Not Canoe)	Rowboat	0.93[a] (0.64)[b]	2.41 (2.55)	0.05 (0.00)	0.96 (1.27)	0.02 (0.00)	0.39 (0.64)	4.76 (5.10)
Open Power	Open Motorboat	27.03 (27.39)	14.29 (14.65)	3.82 (3.82)	5.38 (5.73)	1.71 (1.91)	4.58 (3.82)	56.81 (57.32)
Cabin Power, Houseboat	Cabin Motorboat	11.71 (12.10)	3.32 (3.18)	4.33 (4.46)	0.72 (0.64)	0.14 (0.00)	1.16 (1.27)	21.38 (21.65)
Sail	Sail, Auxiliary Sail	6.48 (4.46)	1.43 (1.27)	0.39 (0.64)	0.48 (0.64)	0.02 (0.00)	0.75 (0.64)	9.55 (7.65)
Canoe (Manually Powered)	Canoe (Manually Powered)	0.38 (0.64)	2.03 (1.91)	0.007 (0.00)	0.21 (0.00)	--- (0.00)	0.15 (0.00)	2.78 (2.55)
Inflatable, Other	Other	1.75 (1.91)	1.61 (1.91)	0.37 (0.64)	0.50 (0.64)	0.06 (0.00)	0.46 (0.64)	4.75 (5.74)
Totals		48.28 (47.14)	25.09 (25.47)	8.97 (9.56)	8.25 (8.92)	1.95 (1.91)	7.49 (7.01)	100.03 (100.01)

[a]Average of percentages calculated from CG-357s for the years 1972, '73, and '74.

[b]Percentage of total accidents coded in ARM .

TABLE 1-2 . PERCENTAGE OF TOTAL ACCIDENTS BY REGION AND JURISDICTION OF WATERS ACCORDING TO CG-357 AND ARM SAMPLE

REGION	STATES IN REGION	JURISDICTION		TOTALS
		STATE	JOINT	
Northwest	Alaska, Idaho, Montana, Oregon, Washington, Wyoming	1.24[a] (1.27)[b]	6.21 (6.37)	7.45 (7.64)
North Central	Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin	11.18 (11.46)	11.18 (11.46)	22.36 (22.92)
Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Virginia, West Virginia	4.35 (4.46)	16.77 (17.20)	21.12 (21.66)
Southwest	Arizona, California, Colorado, Hawaii, Nevada, New Mexico, Utah	4.35 (4.46)	14.29 (14.01)	18.64 (18.47)
South Central	Arkansas, Kansas, Louisiana, Missouri, Oklahoma, Texas	4.97 (3.18)	6.21 (6.37)	11.18 (9.55)
Southeast	Alabama, Georgia, Florida, Mississippi, North Carolina, South Carolina, Tennessee	4.35 (4.46)	14.91 (15.29)	19.26 (19.75)
	TOTALS	30.44 (29.29)	69.57 (70.70)	100.01 (99.99)

[a]Average of percentages calculated from CG-357s for the years 1972, '73 and '74.

[b]Percentage of total accidents coded in ARM_4.

TABLE 1-3. PERCENTAGE OF TOTAL ACCIDENTS BY YEAR OF OCCURRENCE IN THE ARM SAMPLE

	YEAR OF OCCURRENCE							TOTAL
	69	70	71	72	73	74	75	
% of Total in ARM Data	15.92	1.91	19.11	15.29	44.59	2.55	0.64	100.01

data was punched on cards directly from the original coding sheets and each card was verified as it was punched. After all the cards were punched, a computer printout of the data was obtained and again verified against the original coding sheets. In all, 477 accident victims were coded in ARM_4. These 477 cases do not include 129 victims coded for ARM_3.

In order to facilitate the large number of tabulations which were necessary, a program was written which sorts ARM data and computes summary statistics. The program was designed to generate the joint frequency distribution for up to five ARM variables.

In order to generate ARM results which represented meaningful sizes of groups of people, the data in ARM had to be weighted. Each datum in ARM was multiplied by a weighting factor determined by the characteristics of the accident. The number of accidents in the ARM sample was tabulated by boat type and accident type, including the ratio of recoveries to fatalities within each cell. A similar table was made for the same variables for the CG-357 (1975) data. Fatalities in ARM were scaled so that the total number of deaths in each accident type by boat type cell after weighting would match the number of fatalities in that cell in CG-357. This procedure insured that fatalities were appropriately distributed by boat type and accident type after weighting.

The recoveries in ARM were weighted as follows: The ratio of total number of accidents from CG-357 to number of accidents in ARM was computed for each cell in the accident type by boat type table. This ratio was multiplied by the total number of people in the cell in ARM to get the projected total number of people in the cell overall (recoveries and fatalities). The projected fatalities in the cell were subtracted, leaving the projected number of recoveries for each boat type/accident type combination. This number was then divided by the number of recoveries in ARM to get the weighting for the recoveries in ARM, cell by cell.

The weights for fatalities were generally much smaller than for recoveries. The fatality weights ranged from 1.32 to 43.98, while the recovery weights ranged from 22.43 to 137.21. The fact that many of the scaling factors are large indicates that a larger sample size is needed for greater accuracy in future ARM results. With small sample sizes and large scaling factors in some cells, a randomly sampled anomaly in such a cell could lead to considerable error.

1.3 RESULTS

This section presents the weighted ARM data for all the major variables and for selected combinations of variables. Of course, there are many possible combinations of variables which could be used in sorting the ARM data. Not all of these are presented in this report. Those that are presented are most relevant to USCG programs. The data reported below are projected frequencies and percentages recovered (or probabilities of recovery) for the population of reported boating accidents. These data should be regarded as preliminary since they are based on a relatively small sample of accident victims.

1.3.1 Basic Results

Table 1-4 presents the results when the ARM data were sorted by region of the country and jurisdiction (state versus joint). The general trend in the table is for the percentage recovered on joint jurisdiction waters to be higher than on state jurisdiction waters. (This is true in every region.) The marginal data (under "total") present the figures for the individual factors, while the table entries are the data for particular region/jurisdiction combinations. Most of the reported cases in ARM are on joint waters, and the percentage of recoveries ranges from 68.9% on state waters in the southeast to 98.1% on joint waters in the northeast.

Table 1-5 presents the breakdown of accidents in ARM by the month that the accident occurred, in two month intervals. The total number of data points for this breakdown was 17,272, whereas it was 17,267 for Table 1-4. This difference is due to "round-off" errors which occur in each entry of a sort of the ARM data. The more table entries there are, the greater is the chance for a cumulative round-off error. In later ARM sorts, the number of unknowns was relatively large; for these sorts the magnitude of the "unknowns" problem will be shown in the tables. In Table 1-5, there were relatively few accidents in November and December (less than 2% of the total number of victims), and yet these victims had a high probability of recovery. The months of May through August accounted for 56.5% of the total number of victims.

Table 1-6 lists the number of cases and percentage of recoveries for three hour intervals during the day. The table shows that over two-thirds of the victims had their accidents between

TABLE 1-4. REGION BY JURISDICTION

REGION	STATES IN REGION	JURISDICTION		TOTALS
		STATE	JOINT	
Northwest	Alaska, Idaho, Montana, Oregon, Washington, Wyoming	282[a] 89.1[b]	1287 97.1	1569 95.7
North Central	Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin	1704 84.9	1725 85.7	3429 85.3
Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, *Virginia, West Virginia*	1148 92.7	2908 98.1	4056 96.5
Southwest	Arizona, California, Colorado, Hawaii, Nevada, New Mexico, Utah	668 88.1	2628 94.6	3296 93.2
South Central	Arkansas, Kansas, Louisiana, Missouri, Oklahoma, Texas	548 93.8	1314 94.6	1862 94.3
Southeast	Alabama, Georgia, Florida, Mississippi, North Carolina, South Carolina, Tennessee	501 68.9	2454 94.2	2955 89.8
	TOTALS	4851 86.7	12416 93.5	17267 91.6

[a] Number of Victims

[b] Percentage Recovered

TABLE 1-5. MONTH OF OCCURRENCE

Month Group	Number of Victims	Percentage Recovered
January/February	1991	93.0
March/April	3009	89.2
May/June	4326	91.3
July/August	5429	92.5
September/October	2183	91.8
November/December	334	96.2
Total	17272	91.6

TABLE 1-6 . TIME OF DAY (24 hr Clock)

Time of Day	Number of Victims	Percentage Recovered
0030 - 0329	500	98.4
0330 - 0629	279	99.0
0630 - 0929	545	91.6
0930 - 1229	2061	87.5
1230 - 1529	4329	90.9
1530 - 1829	3639	90.3
1830 - 2129	3842	93.6
2130 - 0029	2076	93.7
Total	17271	91.6

1230 and 2129. The percentages recovered are high for the early morning hours (0030 to 0629). This might be due to the way in which people are recovered or some other factor. For example, a victim from the early morning, if recovered, can relate the time of his accident readily. If he dies, the discovering party cannot know when the accident happened, and the tendency might be to note the time the body was recovered or leave the time "unknown."

Table 1-7 shows the frequencies and probabilities of recovery for different rescuing agents by time of day. Several important points concerning ARM results are depicted in this table. The "unknown" category on the "assisting party" variable was listed because there were so many unknowns. The total number of victims, 16,123, is about 1100 less than previous tables. There are about 1100 victims which were recovered by "other" assisting parties. These data were left out of the table. None of the accidents coded in ARM had victims recovered by the auxiliary. All of the victims of accidents coded in ARM who were recovered by the USCG lived. These facts and the small sample sizes in some table cells indicate the severity of the dual problem of unknowns and small sample size. The small overall sample size of 477 actual cases (before weighting) means that not every case can be represented (as indicated by the "0" table entries). The unknown data cause even fewer of the coded victims to be entered into meaningful cells in the table (i.e., cells where both factors are known). In this and ensuing ARM sorts where there are many cells in the table, these problems will be present.

Table 1-8 shows the overall breakdown of the recovery data by assisting party, including the 1137 victims recovered by "other" assisting parties. Again, there were no rescues by the auxiliary and the percentage of recoveries when assisted by the USCG was 100%.

Table 1-9 presents the recovery data and number of victims by boat length, excluding 99 victims which were on boats less than six feet (1.83 m) long. The percentage recovered is relatively high for all categories except "unknown" and boats less than 16 feet (4.88 m) in length. The "unknowns" include some victims who were found drowned and were known to have been boating. Thus, the low percentage of recoveries for unknowns is not surprising.

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TABLE 1-7. TIME OF ACCIDENT AND ASSISTING PARTY

Assisting Party	Time of Accident - 24 Hr Clock												Total	
	0030 - 0429		0430 - 0829		0830 - 1229		1230 - 1629		1630 - 2029		2030 - 0029			
	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered
Boater - Same Boat	117	98.3	2	0	103	80.6	255	69.9	668	90.2	57	70.2	1202	84.7
Boater - Another Boat	6	0	114	87.8	1401	96.7	1705	96.9	1095	98.2	856	99.6	5177	47.2
Coast Guard	83	100.0	0	-	0	-	41	100.0	296	100.0	209	100.0	629	100.0
Coast Guard Auxiliary	0	-	0	-	0	-	0	-	0	-	0	-	0	-
State/Local Officials	0	-	0	-	50	100.0	566	99.3	466	99.4	509	99.5	1591	99.4
No One/ Unknown	418	100.0	217	95.9	613	66.4	2942	85.5	2506	88.1	828	86.9	7524	86.0
Total	624	98.7	333	92.5	2167	87.4	5509	89.8	5031	92.3	2459	94.6	16123	91.4

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TABLE 1-8 . RECOVERY DATA BY ASSISTING PARTY

Assisting Party	Number of Victims	Percentage Recovered
	1205	84.7
Boater from Another Boat	5181	97.2
U.S. Coast Guard	631	100.0
U.S. Coast Guard Aux.	0	-
State/Local Officials	1592	99.4
No One	7162	86.2
Other	1137	95.4
Unknown	363	84.3
Total	17271	91.6

TABLE 1-9 . RECOVERY DATA BY BOAT LENGTH

Boat Length (to nearest ft)	Number of Victims	Percentage Recovered
6 - 10 ft (1.8 - 3.0 m)	172	91.8
11 - 15 ft (3.4 - 4.6 m)	4618	87.1
16 - 17 ft (4.9 - 5.2 m)	4177	94.1
18 - 19 ft (5.5 - 5.8 m)	2256	94.2
20 - 22 ft (6.1 - 6.7 m)	1147	96.8
23 - 25 ft (7.0 - 7.6 m)	1830	97.8
26 - 35 ft (7.9 - 19.7 m)	1619	97.8
36 - 45 ft (11.0 - 13.7 m)	768	100.0
46 ft and Over (14.0 m and Over)	84	98.8
Unknown	498	50.7
Total	17169	91.8

The number of people on board is crossed with boat length in Table 1-10 and the recovery statistics are shown. The percentage recovered increases with increasing boat length, and the percentage recovered is relatively high with four or more people on board. The mean number of people on board tends to increase with boat length in the ARM sample. As before, with so many cells in the table, sample sizes within cells in the table are occassionally small and some cells are empty (have zero entries). Table 1-11 presents the recovery data for number of people on board. There are a few data points included in this table that were not in the previous one because number of people on board or boat length (or both) was unknown. These were principally in the first three categories of number of people on board (length unknown) and "unknown" under number of people on board.

Table 1-12 shows the breakdown of recovery data by the number of PFDs on board. One salient feature of this table is that very few of the victims in the accidents coded in ARM were aboard a boat with only one PFD. Nearly two-thirds of the victims were on boats where the number of PFDs aboard was unknown, and 25% of the known victims were on boats with no PFDs.

The most frequent type of activity by far was pleasure cruising (see Table 1-13). This type of activity also lead to the highest percentage of recoveries (93.9%) with all other activities registering percentages of recovery less than 90%.

As far as body of water is concerned (see Table 1-14), the most frequent categories were rivers/creeks, lakes/swamps, and coastal bays/inlets. The latter category resulted in a high (97.4%) percentage of recoveries, while the percentage of recoveries for the Great Lakes was very low (79.1%).

Table 1-15 lists the recovery data for the ARM-coded victims relative to their distance from shore. The table shows a rapid decrease in the percentage recovered as distance from shore increases beyond one-half mile (0.80 km). The distance from shore was unknown for nearly 23% of the victims.

The next tabulation (Table 1-16) is for the ages and sexes of the victims. Overall, in the ARM data, females survive more often than males, and children have the lowest percentage

TABLE 1-10. BOAT LENGTH AND NUMBER OF POB

Number of People on Board	Boat Length								Total	
	6-15 ft (1.8-4.6 m)		16-19 ft (4.9-5.8 m)		20-25 ft (6.1-7.6 m)		Over 26 ft (7.9 m)			
	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered
1	259	82.0	123	83.7	145	98.0	5	0.0	532	84.8
2	1621	84.1	1091	94.4	391	96.9	360	100.0	3463	90.4
3	1132	79.4	1053	93.6	941	95.3	319	100.0	3445	90.0
4	848	92.2	2252	97.0	700	98.3	599	96.2	4399	96.2
5	362	87.3	229	99.2	209	100.0	463	99.4	1263	96.0
6	301	100.0	853	90.3	0	-	430	98.4	1584	94.3
7	0	-	362	96.2	530	99.3	209	100.0	1101	98.4
8	223	100.0	401	100.0	0	-	0	-	624	100.0
9-18	0	-	0	-	57	94.8	0	-	57	94.8
Total	446	86.2	6364	95.0	2973	97.4	2385	98.4	16468	93.4
Mean No. POB	2.62		3.40		3.12		3.75			

TABLE 1-11. NUMBER OF PEOPLE ON BOARD

Number of People on Board	Number of Victims	Percentage Recovered
1	576	78.3
2	3968	86.2
3	3577	90.1
4	4402	96.2
5	1264	96.1
6	1585	94.4
7	1102	98.4
8-17	682	99.6
Unknown	115	23.5
Total	17271	91.5

TABLE 1-12. NUMBER OF PFDS ON BOARD

Number of PFDs on Board	Number of Victims	Percentage Recovered
0	1619	86.5
1	6	0.0
2	809	90.4
3	493	94.8
4	529	98.0
5	440	89.1
6	558	94.4
7	656	97.6
8-17	1325	99.1
Unknown	10806	90.8
Total	17271	91.6

TABLE 1-13. ACTIVITY OF BOAT

Activity of Boat at Time of Accident	Number of Victims	Percentage Recovered
Pleasure Cruising	12278	93.9
Fishing	2750	85.4
Hunting	125	86.4
Water Skiing	877	88.9
Skin Diving or Swimming (not underway)	0	-
Other	1243	86.6
Total	17273	91.6

TABLE 1-14. BODY OF WATER

Body of Water	Number of Victims	Percentage Recovered
River or Creek	5337	90.8
Lake or Swamp	5830	90.0
Great Lake	806	79.1
Coastal Bay/Inlet	4440	97.4
Ocean	860	90.9
Total	17273	91.6

TABLE 1-15. DISTANCE TO SHORE

Distance to Shore	Number of Victims	Percentage Recovered
0 - 5 Yds (4.6 m)	4552	95.2
5 - 300 Yds (1/6 Mile) (4.6 - 274.3 m)	6847	93.3
1/6 - 1/2 Mile (0.3 - 0.8 km)	1232	95.0
1/2 - 2 Miles (0.8 - 3.2 km)	555	76.1
Greater Than 2 Miles (3.2 km)	136	50.8
Unknown	3951	87.3
Total	17273	91.6

TABLE 1-16. VICTIM'S SEX AND AGE GROUP

Victim's Age Group	Victim's Sex						Total	
	Male		Female		Unknown			
	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered
Adult (19 + Yrs)	10234	90.7	2882	93.5	0	-	13116	91.2
Teenager (12-18 Yrs)	1634	91.6	805	97.9	0	-	2439	93.6
Child (Under 12 Yrs)	325	74.2	279	94.0	139	100.0	743	86.4
Unknown	633	93.4	175	100.0	163	100.0	971	95.7
Total	12826	90.5	4141	94.6	302	100.0	17269	91.6

of recovery. The latter point was especially true of male children, whose recovery rate was a low 74.2%.

Figure 1-6 (p. 1-22) shows the weighted ARM data for the Final Boat Configuration decision tree. In each decision tree, the numbers at the upper right indicate the total number of projected victims and the number of victims for whom all the information in the tree was unknown. In Figure 1-7 there were 505 victims for whom nothing about the final boat configuration was known. For the remaining 16,768 victims, at least enough information was known to make the first decision in the tree. The total number of victims entering each of these nodes and the percentage recovered for each node are shown just outside the node. For example, there were 2583 victims whose boats sank and the recovery rate for those victims was 94.4%. There were many victims for whom only partial information was available.

There are 7091 projected victims at the "upright and not swamped" node, but a total of only 6529 victims at the two nodes directly below ("propelled" and "not propelled"). The remaining 562 victims were known to have been in an upright and not swamped boat, but it was not known whether or not they had propulsion.

Returning to Figure 1-6, one can see that each of the final boat configurations has a relatively high frequency of occurrence except level floating capsized or swamped boats. Capsized or swamped boats that floated level led to a higher percentage of recoveries (94.2%) than did those that were not level (87.9%). Thus, improved flotation, if it resulted in more boats floating level, might improve victims' chances.

The decision tree for the victim's condition is shown in Figure 1-7. As might be expected, the recovery rate for "unconscious" and "seriously injured/inadequate emergency treatment" are very low. There were 9519 conscious victims whose swimming ability was unknown. Thus, the low probabilities of recovery for "swimmer" and "non-swimmer" may reflect conditions that are peculiar to this information being reported. Only 39.3% of the victims (only 6796 out of 17,273) were processed completely through this decision tree.

In the case of the victim's behavior and circumstances (Figure 1-8), there were only 19 unknowns. A total of 52 victims wound up trapped or entangled in the water. All of these

victims died. The remaining 17,201 victims were divided almost evenly between "victims in the boat" and "victims in the water." There was a definite contrast between recovery rates for these two nodes, favoring "in boat" 98.5% to 85.6%. According to ARM, leaving the boat, remaining in the water, swimming for shore, and similar behaviors result in lower probabilities of recovery than the traditionally recommended alternatives of staying with, on, or in the boat and re-entering the boat. In this decision tree a high percentage of victims (96.3%) were coded all the way through the tree.

Table 1-17 shows the recovery data for "time with boat" versus the victim's behavior and circumstances. The categories of "unknown" and "not applicable" on the time variable account for over 60% of the victims in the table. Remaining in the boat led to a high percentage of recoveries, as did re-entering the boat (99.5% and 98.2% respectively), while being in the water but with the boat led to a low percentage of recoveries (78.4%).

Figure 1-9 presents the decision tree for PFD availability and use. Overall, 21.6% of the victims in the tree (3441 out of 15,896) used PFDs, but only 13.3% (2111) were known to have worn a PFD. Many of the wearers donned their PFDs after the accident. The percentage recovered for "PFD worn" is low (82.1%) while the percentage recovered for "donned PFD" (98.3%) is high. Some of the probabilities of recovery in this decision tree are counterintuitive. For example, for "held onto PFD" the probability of recovery is 82.9%, while for "PFD accessible but not used" the probability of recovery is 98.8%. Later sections dealing with benefit estimation will account for some of these problems in terms of variables that are highly correlated with PFD wear or non-wear. Over three-fourths (13,416 out of 17,273 = 77.7%) of the ARM coded victims were processed completely through the PFD availability and use decision tree.

Table 1-18 relates time to the removal or donning of a PFD. Very little data was available concerning the time to removal of a PFD, but all of the ARM victims who removed their PFDs died. The mean time until a PFD was donned was approximately 7.5 minutes for ARM victims. The fact that PFDs were available to be donned appears to have played a significant role for over 1100 people in the weighted ARM data.

TABLE 1-17. BEHAVIOR/CIRCUMSTANCES AND TIME IN/WITH BOAT

	TIME IN/WITH BOAT												TOTAL
	0 - 5 min.		5 - 30 min.		1/2 hr - 2 hr		Over 2 hr		Unknown		N/A		
	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	
Remained In Boat	784	99.5	878	99.4	109	91.8	125	100.0	607	100.0	2561	99.7	5064[a] 99.5[b]
In Boat - Then Swam for Shore, etc.	990	98.0	0	-	43	95.4	50	100.0	0	-	74	71.7	1157 96.3
In Boat - Had to Abandon Boat	679	96.5	296	99.0	85	97.7	43	95.4	513	100.0	698	95.5	2314 97.3
In Water - Re-entered Boat	602	100.0	200	100.0	0	-	0	-	143	100.0	291	92.5	1236 98.2
In Water - with Boat	660	73.5	185	71.4	27	100	34		32	0.0	4362	80.5	5300 78.4
TOTAL	3715	94.0	1559	96.0	264	95.1	252	85.7	1295	97.7	7986	88.3	15071[a] 91.4[b]

[a] Number of Victims

[b] Percentage Recovered

TABLE 1-18. PFD AVAILABILITY/USE AND TIME TILL PFD DONNED/REMOVED

Time Till PFD Donned/Removed	PFD Availability/Use: Removed PFD After Accident: Number of Victims	PFD Availability/Use: Removed PFD After Accident: Percentage Recovered	PFD Availability/Use: Donned PFD After Accident: Number of Victims	PFD Availability/Use: Donned PFD After Accident: Percentage Recovered
0- 2 Minutes	14	0	383	95.9
2- 5 Minutes	0	-	224	100.0
5-15 Minutes	0	-	421	99.3
15-30 Minutes	0	-	86	96.6
30-60 Minutes	0	-	27	100.0
Over 1 Hour	0	-	0	-
Total	14	0	1141	98.1

Table 1-19 is a three variable sort. PFD availability and use, water temperature, and time in the water are cross-tabulated with the table entries being the total number of victims and the percentage recovered for the indicated levels of the three variables. As before, with such a large sort empty table cells are frequent and the sample sizes in cells with data are often small. Over 70% of the water temperatures in the ARM data were unknown, over 42% of the times in the water were unknown or not applicable, and 8% of the PFD availability and use data were unknown or not applicable on this sort. For "PFD worn" versus "no PFD worn," the largest difference in percentage of recoveries for known times in the water occurs in the 0 - 15 minute category (summed across all water temperatures), with PFD wear having the higher percentage of recoveries by 93.0% to 88.4%.

Whether or not the victim's boat had a sufficient number of PFDs under the law was coded in ARM and Table 1-20 shows the breakdown of recovery data accordingly. Over 87% of the victims where the number of PFDs was known had a sufficient number of PFDs. These victims also had a higher probability of recovery than those who did not have a sufficient number of PFDs.

TABLE 1-19. PFD AVAILABILITY/USE BY WATER TEMPERATURE BY TIME IN WATER

PFD AVAILABILITY/USE AND TIME IN WATER		WATER TEMPERATURE									
		31 -50F	(-.55 -10C)	51 -70F	(10.5 -21.1C)	71 -87F	(21.7 -30.5C)	UNKNOWN		TOTAL	
PFD WORN	0-15 Min	0[a]	-[b]	382[a]	96.0[b]	132[a]	75.8[b]	635[a]	94.8[b]	1149[a]	93.0[b]
	15 Min - 2 Hr	0	-	0	-	0	-	174	100.0	174	100.0
	Over 2 Hrs	43	95.4	200	91.5	27	100.0	108	91.7	378	92.6
	Unknown	0	-	50	100.0	0	-	372	96.3	422	96.7
	N/A	0	-	221	99.1	0	-	754	92.8	975	94.1
NO PFD WORN	0-15 Min	594	88.9	1602	94.3	188	79.8	3640	86.1	6024	88.4
	15 Min - 2 Hr	259	92.7	184	92.4	0	-	222	88.7	665	91.3
	Over 2 Hrs	101	82.2	0	-	0	-	320	95.7	421	92.4
	Unknown	72	80.6	0	-	222	93.7	656	72.2	950	77.8
	N/A	50	100.0	413	98.0	423	94.8	3831	97.3	4717	97.2
UNKNOWN	0-15 Min	0	-	0	-	0	-	749	85.3	749	85.3
	15 Min - 2 Hr	0	-	0	-	0	-	53	94.4	53	94.4
	Over 2 Hrs	0	-	0	-	0	-	362	96.2	362	96.2
	Unknown	0	-	0	-	0	-	125	100.0	125	100.0
	N/A	0	-	0	-	0	-	85	97.7	85	97.7
TOTAL		1119	89.4	3052	95.2	992	89.3	12086	91.4	17249	91.8

a Number of Victims
b Percentage Recovered

TABLE 1-20. SUFFICIENT NUMBER OF PFDS

SUFFICIENT NUMBER	NUMBER OF VICTIMS	PERCENTAGE RECOVERED
Yes	12931	93.5
No	1857	87.3
Unknown	2485	85.5
Total	17273	91.6

Figure 1-10 categorizes the types of PFDs or other flotation used by accident victims (regardless of whether they actually entered the water). Only 3413 or 21% of the victims used a PFD of any kind. Of the known victims who used a PFD, 88.7% used a Coast Guard approved PFD and had a high percentage of recoveries (96.1%). Very little information was available in the ARM data concerning the type of PFD used. Less than 21% of the victims for whom the decision tree was applicable were able to be processed completely through the tree.

Tables 1-21 and 1-22 list the recovery data for "PFD malfunction" and "improper PFD use," respectively. These tables indicate that malfunctions and improper use are very infrequent events in the ARM data.

Figure 1-11 shows the decision tree for signalling or distress notification. Slightly less than 5.9% of the victims used signalling devices and another 6.4% had very noticeable boats and/or equipment. These two groups of victims had higher probabilities of recovery than those without signalling equipment. Since there does not appear to be a significant change in probability of recovery from "effective" signal to "ineffective," the higher probability of recovery for those with signals may be due to another factor that correlates highly with having signals available, such as boat size or type.

Table 1-23 presents the recovery data for different intervals of water temperature. There are many unknowns on this variable. For the known data, there is no clear pattern to the percentage of recoveries across water temperatures.

Water temperature by time in the water is tabulated in Table 1-24. For 78.5% of the victims in ARM at least one of these two variables was unknown or not applicable. For the known victims, most of the victims were in 50° - 69°F (4.4° - 20.5°C) water for one-half hour or less.

Table 1-25 lists the recovery data for different water conditions. "Swift current" had the lowest percentage recovered, but this category may be highly correlated with other variables (such as boat type, activity) which influence the percentage of recoveries.

The preceding pages have presented ARM recovery data sorts for all of the major variables coded in ARM, and some of the relevant combinations of variables. Some of the tables have indicated that there are variables that interact with each other, or are highly correlated. These correlations or interactions can lead to counterintuitive results in terms of the probabilities of recovery. One important aspect to this problem is that it means that every benefit estimation problem, or evaluation of a set of conditions, must include a search on other variables than those of direct interest in order to determine interrelationships that may bias the results. Section 1.3.2 below investigates some of these interrelationships for "PFD use."

1.3.2 Interrelationships

The previous pages contained the basic results for the variables coded in ARM. The cross tabulations of two or more variables indicated that there may be significant interactions or correlations between variables. Several of these relationships will be investigated in succeeding pages, particularly those relating to PFD use.

At first glance, Figure 1-9 (PFD availability and use) seems to indicate that the percentage recovered for "PFD worn" (82.1%) is less than for "PFD not worn" (= all other victims, 92.2%). Of course, the latter category includes victims who didn't need a PFD (they never entered the water), victims who donned one after the accident, etc. Even if PFD donners are included in "PFD worn," the percentage of recovered is 91.0% as opposed to 91.7% for all remaining victims. How can an obviously beneficial factor such as wearing a PFD lead to a lower percentage of recoveries overall? Perhaps one or more other factors are related to PFD wear in such a way as to cause an apparent lower percentage of recoveries. This discussion of apparent

TABLE 1-21. PFD MALFUNCTION

MALFUNCTION	NUMBER OF VICTIMS	PERCENTAGE RECOVERED
Yes	3	-
No	3896	94.5
Unknown	431	92.4
Not Applicable	12944	90.8
Total	17274	91.6

TABLE 1-22. IMPROPER PFD USE

IMPROPER USE	NUMBER OF VICTIMS	PERCENTAGE RECOVERED
Yes	32	84.4
No	3412	93.9
Unknown	886	96.0
Not Applicable	12944	90.8
Total	17274	91.6

TABLE 1-23. WATER TEMPERATURE

WATER TEMPERATURE	NUMBER OF VICTIMS	PERCENTAGE RECOVERED
30°-39°F (-1.1°-3.8°C)	116	100.0
40°-49°F (4.4°-9.4°C)	796	87.2
50-59°F (10°-15°C)	1467	93.9
60-69°F (15.5°-20.5°C)	1416	94.8
70-79°F (21.1°-26.1°C)	1025	90.0
80-87°F (26.7°-30.5°C)	357	98.4
Unknown	12095	91.2
Total	17272	91.6

Water temperature by time in the water is tabulated in Table 1-24. For 78.5% of the victims in ARM at least one of these two variables was unknown or not applicable. For the known victims, most of the victims were in 50° - 69°F (4.4° - 20.5°C) water for one-half hour or less.

Table 1-25 lists the recovery data for different water conditions. "Swift current" had the lowest percentage recovered, but this category may be highly correlated with other variables (such as boat type, activity) which influence the percentage of recoveries.

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TABLE 1-24. WATER TEMPERATURE BY TIME IN WATER

Time In Water	WATER TEMPERATURE								Total
	30°-49°F (-1.1°-9.4°C)		50°-69°F (4.4°-20.5°C)		70°-87°F (21.1°-30.5°C)		Unknown		
	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	Number of Victims	Percentage Recovered	
0 - 1/2 Hr	409	82.2	2252	94.7	431	83.3	5274	87.2	8366 [a] 88.8 [b]
1/2 Hr - 2 Hr	253	94.9	0	-	0	-	203	98.6	456 96.5
Over 2 Hr	127	98.5	216	84.3	27	100.0	789	95.4	1159 93.8
Unknown	72	80.6	50	100.0	222	93.7	1154	83.0	1498 85.0
Not Applicable	50	100.0	360	97.2	698	96.7	4670	96.6	5778 96.7
Total	911	88.8	2878	94.3	1378	92.1	12090	91.1	17257 [a] 91.7 [b]

[a] Number of Victims

[b] Percentage Recovered

TABLE 1-25. WATER CONDITIONS

WATER CONDITIONS	NUMBER OF VICTIMS	PERCENTAGE RECOVERED
Calm	8089	92.8
Choppy/Rough	6979	92.2
Swift Current	2204	86.2
Not Applicable	1	0.0
Total	17273	91.6

counterintuitive results will be expanded in the discussion of benefit estimations. As this point it is sufficient to indicate the motivation for investigating the relationships between various factors and PFD use.

Is PFD use related to certain accident types? The ARM data was sorted by PFD use and accident type to investigate this question. PFD use was broken into three categories:

1) didn't have or use a PFD,
2) used a PFD but did not wear it, and
3) wore or donned a PFD.

Accident types were categorized as shown in Table 1-26(A).

TABLE 1-26(A). PFD USE BY ACCIDENT TYPE

PFD USE	ACCIDENT TYPE			Total
	Collisions	Capsizings	All Others	
Didn't Use (No. Victims)	6751	2833	2884	12468
Used, Not Worn (No. Victims)	563	228	500	1291
Worn (No. Victims)	1218	651	261	2130
TOTAL	8532	3712	3645	15889

NOTE: There are approximately 1400 victims unknown on one or more of these variables, thus the total number of victims is only 15,889.

A contingency coefficient of C = 0.113 was computed based upon the data in the table (χ^2 = 206.05, N = 15,889). Of course, the C and χ^2 values are based upon weighted ARM data, and as such are used only to indicate the degree of relatedness of variables. The large χ^2 value is due largely to having proportionally too many "PFD worn" victims in capsizing/swampings and too few in "all others." The "all others" category includes mostly fires, where the percentage recovered is high (greater than 99%), while the percentage recovered for capsizings/swampings is low (81.3%). Thus, there is some evidence that the types of accidents that PFD wearers are involved in contribute to the low percentage recovered for PFD wear since they tend to be more severe accident types.

The number of categories in Table 1-26(A) for each variable, and in the following tables, was limited to insure that each cell had a relatively large sample size. Thus, for some of these tables, categories included two or more possible values of the variable, such as "PFD worn" including those who were wearing before the accident and those who donned after.

Is water temperature related to PFD wear? Table 1-26(B) shows the number of victims under each PFD use category for different water temperatures. The data are reported only for those cases where PFD use and water temperature were known. The contingency coefficient for this table is C = 0.088 (χ^2 = 39.94, N = 5173), with most of the χ^2 value due to there being so few victims in warm water under "PFD used but not worn."

TABLE 1-26(B). PFD USE VS. WATER TEMPERATURE

		Water Temperature		
		31 - 70°F	71°F +	TOTAL
PFD	Not Used	3231	821	4052
	Used, Not Worn	269	14	283
	Worn	678	160	838
	TOTAL	4178	995	5173

Water conditions by PFD use lead to the frequency (number of victims) data shown in Table 1-26(C). The contingency coefficient for those data was C = 0.070 (χ^2 = 77.91, N = 15,891), with the major contribution to the χ^2 value coming from too many wearers in rough water and too few in calm. This appears to be another factor whose relationship with PFD wear leads to a lower percentage recovered for PFD wear overall than for "No PFD."

TABLE 1-26(C). PFD USE BY WATER CONDITION

		Water Conditions		
		Calm	Rough*	Total
PFD	Not Used	5962	6505	12,468
PFD	Used, Not Worn	588	703	1,291
PFD	Worn	800	1332	2,132
PFD	TOTAL	7350	8541	15,891

* Includes swift current, choppy, rough

Table 1-26(D) has the number of victims for combinations of PFD use and victim's conditions. The contingency coefficient for these data was C = 0.177 (χ^2 = 511.59, N = 15,821). The three largest contributions to the χ^2 value were from having proportionally too many swimmers not using, too few swimmers wearing, and too many not seriously injured/conscious wearing. Again, there is some evidence that severe levels of this variable (victim's condition) is contributing to lowering the percentage recovered overall for PFD wear.

TABLE 1-26(D). PFD USE BY VICTIM'S CONDITION

		VICTIM'S CONDITION				
		Seriously Injured/ Unconscious	Not Seriously Injured/ Conscious	Non-Swimmer	Swimmer	TOTAL
PFD	Not Used	1505	6407	194	4301	12,407
PFD	Used, Not Worn	159	807	14	310	1,290
PFD	Worn	307	1516	60	241	2,124
PFD	TOTAL	1971	8730	268	4852	15,821

Final boat configuration by PFD use is shown in Table 1-26(E). These data lead to a contingency coefficient of C = 0.185 (χ^2 = 550.3, N = 15,544), with the major contributions to the χ^2 due to too few victims in "used, not worn" under "sunk," too few victims for "worn" under "upright, not swamped," and too many victims for "worn" under capsized/swamped." The final boat configuration data indicate that PFD wear is related to severe conditions (capsized/swamped) and not to less severe conditions (upright, not swamped).

TABLE 1-26(E). PFD USE BY FINAL BOAT CONFIGURATION

		FINAL BOAT CONFIGURATION			
		Upright, not Swamped	Capsized/ Swamped	Sunk	TOTAL
PFD	Not Used	5866	5027	1321	12,124
	Used, not Worn	593	375	322	1,290
	Worn	608	1225	297	2,130
	TOTAL	7067	6627	1850	15,544

PFD use is tabulated with the victim's behavior and circumstances in Table 1-26(F). The contingency coefficient for these data is C = 0.279 (χ^2 = 1336.38, N = 15,863). There were many cells which contributed considerably to the χ^2 value. If behavior/circumstances is dichotomized into the three less severe categories (on the left in the table) as opposed to the three more severe categories (on the right), then there tends to be too many wearers in the more severe categories overall, and too few in the less severe.

TABLE 1-26(F). PFD USE BY BEHAVIOR/CIRCUMSTANCES

		BEHAVIOR/CIRCUMSTANCES						
		In Boat	Remained on/ With Boat	Re-entered Boat	Separated From Boat	Swam For Shore	All Others	TOTAL
PFD	Not Used	4127	1024	1048	1815	1823	2612	12449
	Used, Not Worn	322	50	122	591	116	90	1291
	Worn	379	163	352	570	85	574	2123
	TOTAL	4828	1237	1522	2976	2024	3276	15863

Finally, Table 1-26(G) presents the number of victims for each boat type by PFD use. For this table, the contingency coefficient C = 0.345 (χ^2 = 2139.46, N = 15,884) was higher than those calculated previously. Almost every cell in the table contributed to the χ^2 being so large. For example, there were proportionally too few wearers in open powerboats and too many people who didn't use PFDs. So many cells in this table contribute significantly to the χ^2 that no overall pattern of bias favoring PFD wear or non-wear is easily discerned.

TABLE 1-26(G). PFD USE BY BOAT TYPE

	Open Power	Cabin Cruiser/ Houseboat	Sailboat	All Others	TOTAL
Not Used	8240	2049	917	1260	12,466
Used, Not Worn	709	329	212	40	1,290
Worn	612	1269	137	110	2,128
TOTAL	9561	3647	1266	1410	15,884

The comparisons on the preceding pages suggest several conclusions:

1) *variables within ARM tend to correlate and interact with each other,* particularly variables such as PFD usage

2) methods are available for measuring the degrees of interrelationship (through the contingency coefficients and χ^2 values) based upon the weighted data, and

3) the implications of these interrelationships bear directly upon benefit estimation.

The last point will be expounded upon in succeeding pages. At this point, it is clear that the apparent effect of changing from one category to another on a given variable (say, from not wearing a PFD to wearing) in terms of the change in percentage recovered, may be biased by the other variables which interact with the given variable (such as Behavior, Boat Type, etc., for PFD use).

1.4 BENEFIT ESTIMATION METHODS AND PROBLEMS

The process of benefit estimation using ARM involves mathematically "transferring" victims from less desirable nodes or states to more desirable states. For instance, "PFD use" might be the more desirable node and "PFD non-use" the less desirable node. To say that a state A is more desirable than a state B means $P_A > P_B$ (other things being equal) where P_A is the recovery probability of a victim in state A and P_B is the recovery probability of a victim in state B.

To calculate the anticipated benefits ϕ of a contemplated regulation, educational program, etc., one must estimate the number of accident victims who might be affected. For instance, we might estimate that, as a result of an education program, 30% of the boating accident victims who would otherwise abandon their boats would instead remain with them. This 30% would be the transfer rate of victims from the state B of abandoning the boat to the state A of remaining with the boat. The benefit ϕ (in number of lives saved annually) is then merely given by the number of victims transferred annually times the increase in the recovery probability as a result of the transfer.

To express this mathematically, let b represent the annual number of victims in state B and r represent the proportion of those victims transferred to state A. Then (rb) is the annual number of victims transferred to state A, and the estimated benefit ϕ in annual number of lives saved is given by

$$\phi = rb\,(P_A - P_B). \tag{1}$$

This equation is useful only under two very restrictive assumptions:

a) the probability of being in state B as opposed to A is statistically independent of other factors which affect the probability of recovery, and

b) the probability that the regulatory program of interest would transfer a victim from state B to A is independent of other factors which affect the probability of recovery.

In the case of PFD wear, this assumption means that the proportion of victims wearing PFDs should be the same for victims who were swimmers and non-swimmers, for accidents in rough and calm water, etc. The previously discussed results show that these conditions were not true.

According to the ARM results, PFD wear was strongly associated with "severe" conditions, i.e., conditions where the probability of recovery is low. Boaters apparently do not don PFDs unless and until they are in serious trouble. This fact makes PFD wear look detrimental in the overall tabulation of ARM results. In Figure 1-9, for example, the probability of recovery for victims wearing a PFD is lower than that of victims who had no PFD available. This result occurs because the group wearing PFDs and the group with no PFD available differ on other dimensions. Those victims wearing PFDs were in much more severe circumstances, so naturally their probability of recovery is lower.

The benefit of increasing PFD wear calculated by using the overall probabilities of recovery for victims wearing and not wearing PFDs (as in equation (1)) would be incorrect. This is because equation (1) assumes that nothing other than PFD wear changes in "transferring" a victim from node B to node A. In fact, as we have seen, conditions are very different for victims wearing and not wearing PFDs.

In order to accurately estimate the benefit of PFD wear, the probabilities of recovery must be compared under comparable conditions. Conditions can be made more nearly comparable by breaking the ARM sample down into subsamples. Benefits can then be calculated separately for each subsample and summed to obtain the overall benefit. For example, the benefit of PFD wear versus non-wear can be compared for victims who were non-swimmers and whose boat capsized in rough water. It is mathematically possible that PFD wear might lead to positive benefits in each such subsample, even though the overall probabilities of recovery suggest that PFD wear is detrimental.

The first step in benefit estimation in the present work was to determine what variables are strongly associated with the frequency of PFD wear. These variables were then used to define subsamples of the total ARM sample. Only factors associated with PFD wear need be considered since only they can distort the estimated benefit of PFD wear versus non-wear. The second step was to apply equation (1) to each subsample to calculate a benefit for those conditions. Equation (1) can reasonably be applied to each subsample because within each subsample the assumptions discussed above are more closely approximated. The benefits for the subsamples

can then be summed to obtain the overall benefits. This discussion greatly oversimplifies the benefit estimation process. There are a number of additional considerations peculiar to each problem. The following discussion outlines such considerations for the estimation of benefits associated with PFD use.

1.4.1 Benefit Estimation Problem: PFD Use

Estimating the benefit from increasing PFD wear is not possible without assuming something about the relationship between wear rate and "holding" rate. If PFD wear were increased to 20%, what would happen to the rate of holding (but not donning) a PFD? Are "donners" wearers or holders? What follows is a discussion of the benefits of PFD use, where a PFD user was any victim who used a PFD by wearing it, holding it, or otherwise.

Several factors were tabulated against PFD use. Two factors which lead to high χ^2 values were used in a three factor tabulation for the benefit estimation with the third factor being PFD use. These two factors were the final boat configuration and the victim's behavior. They were chosen because of their significant relationship with PFD use, the ease and sensibility of combining categories within these variables, and the sample sizes within categories on these variables. The final boat configurations were grouped into three categories: capsized and/or swamped, sunk, and all others. Behaviors were ranked according to severity and grouped into the more severe, or inappropriate behaviors, and less severe, or appropriate behaviors. Behaviors where PFDs should not have any influence on the probability of recovery were excluded. These included occasions where the victims remained in a level non-swamped boat, and similar conditions. PFD use was broken down into three categories: those without a PFD, those who used a PFD but did not wear it or took it off, and those who wore or donned a PFD. The number of categories for each factor was limited by the necessity of having an adequate sample in each table entry.

To generate lower and upper bounds for benefits, one merely needs to consult the cells in the three factor table and assess the number of people recovered under certain assumptions. For the lower bound on the number of people recovered, the total number of victims in each cell is multiplied by the probability of recovery for "no PFD" within the cell. Summing these recoveries across cells gives the number of people recovered overall if no one had or used a

PFD. The tabulation of recovery data for PFD use by final boat configuration by behavior/circumstances is shown in Table 1-27, excluding those behaviors and circumstances where PFDs should not play a role in probability of recovery.

To calculate the estimate of the total number of people recovered if there were no PFDs, multiply the number of people in each cell by the probability or recovery for "PFD not used" within that cell. The equation below summarizes this procedure.

$$\text{Total Recovered/No PFD Used} = (3455)\,(0.808) + \ldots + (1368)\,(0.957) = 8204$$

There are 9456 total victims in the table, thus, based upon the ARM data, the recovery rate with no PFD used in cases where the victims were in the water during their accidents is 8204/9456 = 0.868.

What are the current benefits of PFDs? According to ARM, 8247 people are recovered with the present use rate (i.e., with the current numbers of people wearing, holding, and otherwise using PFDs). This leads to an estimate that 8247 - 8204 = 43 people per year are currently being saved by PFDs.

What are the maximal benefits of PFD use? With every victim using a PFD, one must assume something about how many hold and how many wear. Using the probabilities of recovery in Table 1-27 for "PFD use" in the calculations is equivalent to assuming that if everyone used a PFD, the same ratio of "used, not worn" to "worn" would persist. Under that assumption, the benefits for 100% use are given by the equation below, which multiplies the number of

$$\text{Benefits for 100\% Use} = (3455)\,(0.802) + \ldots + (1368)\,(1.000) - 8204 = 108$$

victims in each cell by the probability of recovery for "PFD used" within the cell. The equation indicates that 108 lives would be saved per year under these assumptions over the number recovered if there were no PFDs used, or 108 - 43 = 65 lives more than are currently saved by PFD use. The PFD <u>use rate</u> is the rate at which victims are wearing or otherwise have direct contact or access to PFDs at the onset of or during an accident.

TABLE 1-27. PFD USE x FINAL BOAT CONFIGURATION x BEHAVIOR/CIRCUMSTANCES

			FINAL BOAT CONFIGURATION					
			CAPSIZED/SWAMPED		SUNK		ALL OTHERS	
BEHAVIOR/ CIRCUMSTANCES:			SEVERE[a]	LESS SEVERE[b]	SEVERE[a]	LESS SEVERE[b]	SEVERE[a]	LESS SEVERE[b]
CELL NUMBER:			1	2	3	4	5	6
PFD USE	NOT USED	Number of Victims	2,802	1,742	855	202	601	752
PFD USE	NOT USED	Probability of Recovery	0.808	0.960	0.877	0.976	0.566	0.957
PFD USE	USED (INCL. WORN)	Number of Victims	653	571	119	448	95	616
PFD USE	USED (INCL. WORN)	Probability of Recovery	0.802	0.993	0.908	0.962	0.527	1.000
PFD USE	**Total Number of Victims Above**		3,455	2,313	974	650	696	1,368
PFD USE	WORN	Probability of Recovery	0.840	0.987	0.941	0.988	0.527	1.000

[a] Includes those conditions coded as 6, 8, 9, 10, 11, 14, 22 and 32 in Figure 1-8.

[b] Includes those conditions coded as 2, 3, 5, 7, 12, 13 and 21 in Figure 1-8.

A similar calculation can be made assuming all of the victims in each cell <u>wear</u> the PFDs (using the probabilities of recovery for wear in each cell), as shown below. The results of this calculation show 100% PFD wear saving 275 lives over not having any PFDs or 232 lives over the current situation. It should be noted that the breakdown of PFD wear by final boat configuration and behavior/circumstances had very small weighted sample sizes in two cells (less than 100 victims in one case and only 11 in another).

$$\text{Benefits for 100\% Wear} = (3455)(0.840) + \ldots + (1368)(1.000) = 8479 - 8204 = 275$$

In the example of PFD use several problems in benefit estimation have surfaced. Critical among these is the problem that certain factors interact significantly with PFD wear (i.e., there are other factors which have certain conditions that correlate significantly with PFD wear or use and thereby bias the probability of recovery for PFD wear or use) and the problem of inadequate sample sizes on some variable sorts. The discussion above has presented approximate benefit estimates for certain boundary conditions (e.g., assuming that everyone wears a PFD, or no one uses a PFD). How do we go beyond these approximate procedures to estimates for specific proposals and more accurate estimates of the bounds?

Suppose, for example, that one proposes through a program to raise the overall base PFD use rate to 50% (where "use" includes wearing and holding a PFD). Let us call this new base use rate β. This means that regardless of the conditions, at least 50% of the victims would use PFDs after the program was in effect. Let α be the "old," or current base use rate (this would be the lowest current use rate under any combination of conditions considered in ARM). It may be true that there are situations which could lead to a use rate within those conditions that was less than α. For example, extreme heat and humidity might lead to a use rate that was lower than the base use rate (i.e., some people who would normally wear PFDs might take them off or not use them because of the severe heat). For simplicity, we will assume that such sub-α situations are infrequent and do not result in significant changes in use rate. Under this assumption, α can be found by searching the tabulation of factors to be used in the benefit estimation problem cell by cell to find the cell with the lowest percentage of PFD users among its victims. This percentage would then be α, the base use rate. Cells which have use rates greater than α would be cells where the conditions are contributing to

the use rate; i.e., more people are using PFDs in those cells because of the levels of certain factors (such as bad weather, etc.). The problem, then, is to account for those who are responding to the conditions. When we increase the basic use rate from α to β, the assumption used in the following calculations is that the number that are responding to the conditions will not change; i.e., changing the base use rate affects only the "non-users" from before the change.

Let A_i be the state of PFD use (a_i = number of PFD users) in cell i, and let B_i be the state of not using a PFD (b_i = number of victims not using a PFD) in cell i. For cells where the conditions contribute to the use rate being greater than α, let γ_i be the rate at which people respond to the conditions in cell i. The assumption that the base use rate α is equal to the use rate in the cell with the smallest use rate is equivalent to the assumption that all γ_i's ≥ 0 and γ_i for the cell with the lowest use rate equals zero. With this notation, the number of users in cell i depends upon the base rate of PFD use α, the rate of responding to conditions in cell i by using a PFD γ_i, and the number of people in the cell $a_i + b_i$, as shown in Equation (2).

$$a_i = \alpha(a_i+b_i) + \gamma_i(1-\alpha)(a_i+b_i) = (a_i+b_i)(\alpha+\gamma_i-\alpha\gamma_i) \tag{2}$$

For the cell which determines α, $\gamma_i = 0$, thus

$$a_i = \alpha(a_i+b_i) \Rightarrow \alpha = \frac{a_i}{a_i+b_i} \tag{3}$$

The b_i values can be determined as shown in Equation (4).

$$b_i = (1-\alpha)(a_i+b_i) - \gamma_i(1-\alpha)(a_i+b_i) = (a_i+b_i)(1-\alpha)(1-\gamma_i) \tag{4}$$

Using either equation (2) or (4), an equation for γ_i can be derived.

$$\gamma_i = 1 - \frac{b_i}{(1-\alpha)(a_i+b_i)} \tag{5}$$

After the proposed program to increase the base use rate has taken effect, β replaces α and the new numbers of users (a_i') and non-users (b_i') can be calculated by Equations

$$a_i' = (a_i + b_i)(\beta + \gamma_i - \beta\gamma_i) \tag{6}$$

$$b_i' = (a_i + b_i)(1 - \beta)(1 - \gamma_i) \tag{7}$$

The benefit for the proposed program can be found by multiplying the probabilities of recovery for using and not using PFDs by the changes in the numbers of people using and not using, cell by cell, and as shown in Equation (8).

$$\phi = \text{Benefit} = \sum_{\text{all } i} P_{A_i}(a_i' - a_i) + P_{B_i}(b_i' - b_i) \tag{8}$$

But, since the total number of victims is constant,

$$(a_i' - a_i) = (b_i - b_i') \tag{9}$$

so Equation (8) reduces to

$$\phi = \sum_{\text{all } i} (P_{A_i} - P_{B_i})(a_i' - a_i) \tag{10}$$

or, the change in probability times the number of people affected, summed across all cells. Equation (10) is very similar to Equation (1), where r was the rate of transfer from state B to state A. This raises the question of the relationship between r, the rate of transfer, and β, the new base use rate. Under the assumption of the γ_i's remaining constant, Equation (5) can be modified to reflect the state of affairs after the proposed program, as shown in Equation (11), since $(1 - r)\,b_i$ victims will remain in state B.

$$\gamma_i = 1 - \frac{(1 - r)\,b_i}{(1 - \beta)(a_i + b_i)} \tag{11}$$

Setting the right size of Equation (5) and (11) equal to each other yields (after reducing),

$$(1-\beta) = (1-r)(1-\alpha)$$

$$\text{or,} \quad r = \frac{(\beta-\alpha)}{(1-\alpha)} \tag{12}$$

One can alter Equation (10) to a better computational form by substituting for a_i and a_i' according to Equations (2) and (6).

$$\phi = \sum_{\text{all } i} (P_{A_i} - P_{B_i})(\beta-\alpha)(1-\gamma_i)(a_i + b_i) \tag{13}$$

Both Equations (10) and (13) calculate the benefits as measured from the current state of affairs (with base PFD use rate = $\alpha \neq 0$). Comparing Equation (1) with Equation (13), by using Equation (12) to substitute for r, it can be seen that the benefit from Equation (13) equals the benefit from Equation (1), cell by cell. Thus, Equation (13) takes into account the fact that, under the constant γ_i's assumption, those people who respond to conditions by using PFDs are not affected by the change in base use rate. So the two equations measure benefits from the current base rate.

The γ_i's, a_i's, b_i's, and α are all quantities which are calculated or drawn from ARM recovery data. The benefits are calculated cell by cell and summed to arrive at the total benefit resulting from the proposed change. The benefit estimation is not biased by those factors that are used to define the cells. At present, the ARM program only sorts on three variables at a time, and more data needs to be coded to allow for more cells to have entries in larger sorts. It is probable that some of the other variables that were found to be strongly related to PFD use (such as boat type, water conditions, etc.) also bias the benefit estimation to some extent.

It can be shown mathematically that under the stated assumptions the method of benefit estimation that was just outlined will generate benefits as a linear function of the base PFD use rate. This linear function is given by Equation (14), where all variables

$$\phi = \sum_{\text{all } i} (a_i + b_i)\, \gamma_i (P_{A_i} - P_{B_i}) + \alpha \left[\sum_{\text{all } i} (a_i + b_i)(1 - \gamma_i)(P_{A_i} - P_{B_i}) \right] \quad (14)$$

are defined as before, with α representing the base use rate for which the benefit is to be calculated. Equation (14) calculates the benefits as measured from a base PFD use rate $\alpha = 0$, assuming no one used PFDs.

In the ARM data for PFD use by final boat configuration by behavior/circumstances, the cell with the lowest use rate was one not shown in Table 1-27 since the victims were in level, upright, non-swamped boats (PFDs should not affect their probability of recovery). The base PFD use rate, determined from this cell, was $\alpha = 0.098$. Using α and the a_i's and b_i's from Table 1-27, the γ_i's can be calculated from Equation (5). Suppose a program were proposed which would change the base PFD use rate to $= 0.50$. Then the benefits for such a program could be calculated using Equation (13), cell by cell, and summed. Under this benefit calculation methodology, 33 additional lives would be saved each year by increasing the base PFD use rate to 50% from 9.8%. Similarly, by using Equation (13), we find that an estimated 68 people per year are saved by the 50% base use rate over the number that would be recovered if no one used PFDs.

Actually, there are several kinds of benefits. In the paragraph above the benefits from the present base use rate and the benefits from "no one using PFDs" were presented. Figure 1-12 presents the graph of number of lives saved plotted against the base PFD use rate according to Equation (13). The ordinate intercept is determined by that part of the equation that is independent of α (at the ordinate intercept $\alpha = 0$) and is computed from the a_i's, b_i's, γ_i's and probabilities of recovery. This intercept (+27 lives saved per year) represents those people who are saved solely by responding to their environmental conditions by using a PFD. These people are saved by the fact that a PFD was available when they decided that they needed to use one. The availability portion of the benefit estimation function is constant since the γ_i's were assumed to be constant. Approximately eight lives more per year are saved by the current base use rate $\alpha = 0.098$. The estimate of 35 lives saved per year by the current PFD use rate is a better estimate than the previously calculated 43 lives per year since this method accounts for those who use in response to conditions. For the proposed program, α would

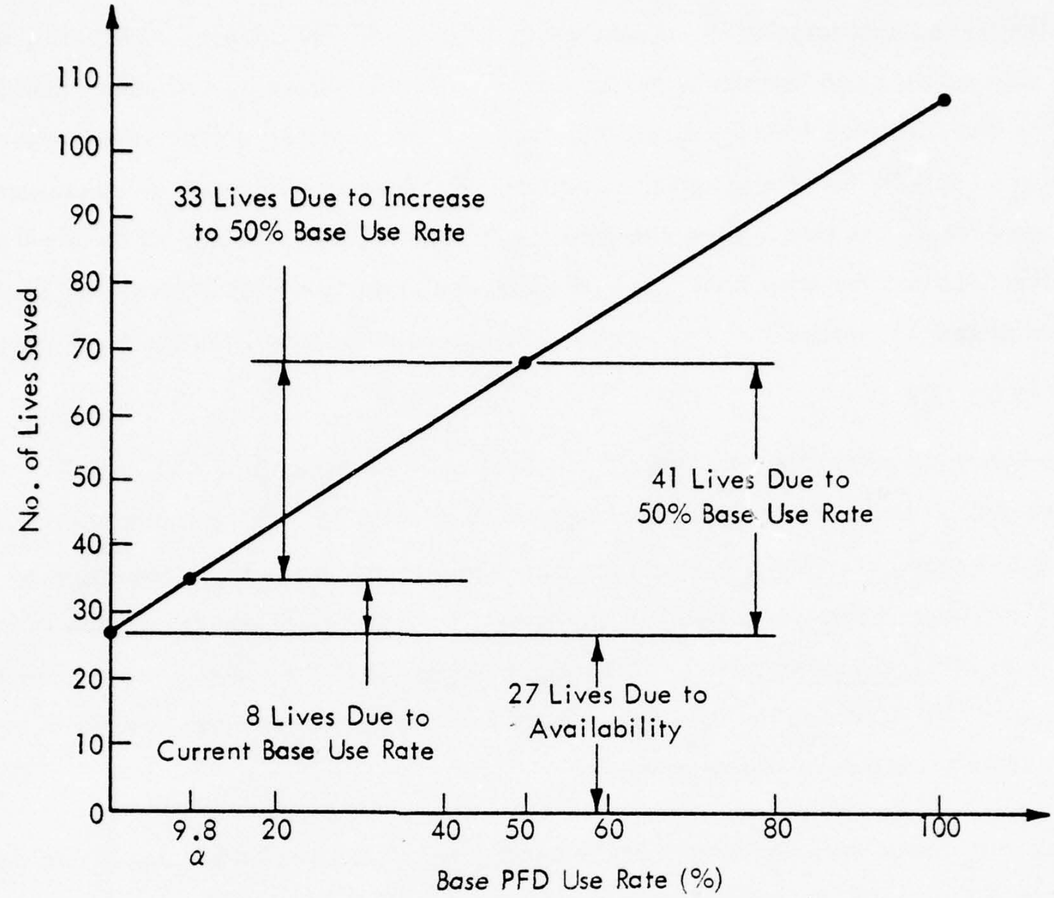

FIGURE 1-12. BENEFIT ESTIMATION FUNCTION: PFD USE RATE

change to 0.50, and several benefits could be discussed. First, 68 total lives are saved each year by a 50% base use rate over not having any PFDs. A total of 41 lives yer year are saved by the 50% base rate over those saved by availability; i.e., 41 lives per year are saved by the base rate effects. Finally, 33 lives per year are saved by the increase in base rate over the present base rate. Of critical interest in cost/benefit problems would be the slope of 0.81 lives saved per year per percent increase in base PFD use rate over the 27 lives saved due to availability.

In the preceding discussion it was assumed that the γ's did not change. Of course, when a program results in an increase in the base PFD use rate, it probably will affect the PFD availability also. This would imply changes in the γ_i's. For example, some of those who normally use PFDs only in response to certain conditions may decide, as a result of the proposed program, to use PFDs all the time. Thus, the increase in base PFD use rate may coincide with a decrease in the γ_i's. On the other hand, some of those who never used PFDs before, may decide to use them in certain circumstances as a result of the proposed program, thereby tending to increase the γ_i's.

A program can affect the base rate, or the availability function (the γ's), or both. It is conceivable that a program could be designed to affect a boater's perception of or fear of certain conditions. Thus, he would be more likely to respond to those conditions by making a PFD available. This would result in an increase in the γ values and an increase in the number of lives saved without necessarily affecting the base rate. Therefore, when a program is proposed, its effects on the base rate and the γ values must be assessed in order to evaluate the benefit function for the program.

Again, it should be remembered that the benefit estimations are based upon the data generated by weighting the 477 recovery scenarios processed through ARM, and may not reflect the benefit estimations generated in the future when the ARM data base has been expanded.

1.4.2 Benefit Estimation Problem: Staying with the Boat

Over 75% of the fatalities in the ARM data are victims who died when not with their boats. What is the benefit of staying with the boat? The ARM data do not include any level flotation boats, although some of the boats in accidents coded in ARM did float level. Therefore, the benefits estimated for this problem are those due to victims staying with non-level flotation boats.

Returning to the basic estimation procedure as outlined in the beginning of Section 1.4, the ARM victims were dichotomized according to those victims who stayed in, on, or with their boats (including those who lost their grip while holding, etc., but stayed until then), and those victims who left their boats (including those who abandoned due to fire, fell overboard, etc.).

The data for this sort are shown in Table 1-28). Based upon these data, if everyone were

TABLE 1-28. STAYING WITH BOAT RECOVERY DATA

	Stayed with Boat	Not With Boat	TOTAL
No. of Victims	9798	7208	17,006
Probability of Recovery	0.970	0.858	92.3

separated from his boat (in the same ratio of falls overboard: abandoned: swam for shore, etc.), 2415 fatalities would result (= (17,006) (1 - 0.858)). If everyone stayed with their boats (again, in the same proportions by category), 510 deaths would result (= (17,006) (1 - 0.970)). With the current breakdown, there are 1321 deaths. Thus, by this estimation procedure, 2415 - 1321 = 1094 people per year are being saved by staying with their boats, while an additional 1094 - 510 = 584 lives could be saved if everyone stayed with their boats.

This example raises several issues. First of all, there may be other variables related to staying with the boat which are biasing the benefit estimation, as with PFDs. In this case, since the benefits appear to be large, the related variables may be biasing the result in favor of staying with the boat. For example, victims may stay with upright boats, large boats, in daylight hours, etc., while leaving capsized, small boats at night. In addition, the dichotomization included people who did not have the choice of whether to leave or not (abandoned due to fire, fell overboard, etc.). Thus, at the least, the sort needs to be reduced in scope to those victims who chose to leave the boat as opposed to those who chose to stay. These points were raised to indicate that benefit estimation, by its nature, requires some judgement as to where the benefits are to be estimated within the sphere of areas of potential benefit. In both examples so far, the ARM data universe has been reduced to only those cases where the beneficial factor or element should have an effect.

Considering only those victims who eventually <u>enter the water</u> (and are <u>not</u> falls overboard victims; i.e., they had to <u>choose</u> to stay or to leave), the benefit estimations change radically Table 1-29 shows the data for the new sort. With these data 621 deaths ((8697) (1 - 0.931))

TABLE 1-29. STAYING VS. LEAVING THE BOAT: BY CHOICE

	Victim Stayed with Boat	Victim Left Boat	TOTAL
No. of Victims	4626	4071	8697
Probability of Recovery	0.942	0.931	0.937

ensue if everyone left his boat, 522 deaths occur if everyone stayed with his boat, and currently there are 569 deaths. Therefore, 621 - 569 = 52 lives per year are being saved by staying with the boat, while 99 lives per year would be saved if everyone stayed with his boat.

This benefit estimation problem can be treated with the same methodology as PFD use (i.e., find related factors, plot the linear benefit estimation function, etc.) in the future as more data become coded into ARM. Such a methodology should be employed when data permit even in cases where the overall result seems favorable, such as staying with the boat, in order to investigate the possible biasing factors in the indicated benefit.

In the case of staying with the boat, the base rate would be composed of those people who stay with their boats in the event of an accident regardless of the conditions specified in the variables used in the ARM sort, while the γ benefit (the benefit due to "availability" in the PFD example) would be due to staying with the boat in response to "conditions" (where "conditions" could include boat type, flotation on board, distance from shore, etc.). Then the benefits could be plotted against base "staying with the boat" rate in a similar manner to the PFD benefit estimation function.

1.4.3 Benefit Estimation Problem: Hypothermia/PFDs

The major effect of hypothermia, as suggested by the sudden drownings research (see Section 3.0), may be due to enough exposure to cold to cause disorientation and drowning rather than enough to cause death from hypothermia per se. Over three-fourths of the water temperature data in ARM are unknown, which hampers research efforts in hypothermia using ARM. Table

1-30 lists the probabilities of recovery for PFD use categories at temperatures where hypothermia for the average person could occur (less than 72°F) and at higher temperatures. Even with only six cells in the table, two of the entries are unknown. If temperature is broken down into

TABLE 1-30. PROBABILITIES OF RECOVERY FOR PFD USE BY WATER TEMPERATURE

	PFD USE		
	Worn	Used, Not Worn	No PFD
Water Temperature ≥73° F	0.799	Unknown	Unknown
Water Temperature ≤72° F	0.946	1.000	0.942

several categories, there is some tendency for the probabilities of recovery at lower temperatures to be low, but the sample sizes are small (many cells have no victims) and the data are variable. As can be seen in Table 1-30, there are low probabilities of recovery for higher water temperatures as well. The table indicates that there is little evidence, if any, of a relationship between PFD use and probability of recovery at lower water temperatures. There is no evidence that PFDs provide hypothermia protection, and they are not designed to do so.

When the time the victim is in the water is included in the data sort, one finds that over 75% of the victims who wind up in the water for whom water temperature and time in the water are known, die or are recovered within 15 minutes, and less than 10% of the victims are in the water more than two hours. The latter group accounts for a projected 78 deaths per year, at all water temperatures, whereas the first 15 minutes account for almost 900 deaths per year. These figures imply that the most serious problems are events during the first few minutes of an accident rather than hypothermia from prolonged exposure. It was found that the largest difference in probabilities of recovery favoring PFD wear over non-use occurred in the 0 - 15 minute category on the time in the water variable.

As mentioned previously, the subject of hypothermia is difficult to investigate in the ARM data because there are thousands of unknowns. There is reason to suspect that the known

victims are likely to be survivors. When an accident victim dies and is discovered some time later, who knows (or cares) what the water temperature was at the time of death or how long he was exposed? It may be true that for this reason the unknowns are associated to a degree with more severe conditions on other variables which could influence the probabilities of recovery given PFD wear, etc.

1.4.4 Benefit Estimation Problem: Level Flotation

There are no level flotation boats in the ARM sample. The analysis which follows deals with boats which floated level when capsized or swamped (despite the fact that they may not have been designed to do so). Table 1-31 below shows the data for all boats which capsized or swamped, indicating those that floated level.

TABLE 1-31. LEVEL FLOTATION RECOVERY DATA

	Capsized/Swamped		
	Floated Level	Not Level	TOTAL
No. of Victims	869	6225	7094
Probability of Recovery	0.942	0.879	0.887

The data indicate that 12.2% of the non-level flotation boats floated level when capsized or swamped. Using the benefit estimation technique outlined in the beginning of the PFD use example, there are currently 55 lives saved per year by boats floating level that have capsized or swamped (these are people who would die if no boats floated level). If all boats floated level, then 447 lives would be saved over not having any boats float level (= (7094) (0.942 - 0.879)). Of course, this estimation procedure assumes that all other variables remain relatively constant when people are transferred from not floating level to floating level. This assumption violates intuition since it is reasonable that weather conditions, number of people on board, etc., would influence the probability that the boat would float level. Here again, a complete analysis once more data are available in ARM should include accounting for related variables and the base level flotation rate (boats floating level which were not designed to the level flotation standards).

1.4.5 Conclusions to Benefit Estimation

Many problems in benefit estimation have arisen in the preceding pages and some solutions have been proposed. The PFD use example was treated in great detail in order to indicate the complicated nature of attempting to estimate the benefits for variables which are highly interrelated. The methodology proposed in that example allows for some powerful conclusions to be drawn in terms of lives saved due to availability as opposed to lives saved by the base use rate, etc. However, that methodology also involves several assumptions; critical among these is the assumption that the percentage of victims responding to conditions by using a PFD does not change as the base rate changes.

Four major problem areas that are in need of further attention are: increasing the ARM data base and sorting capabilities, investigating the implications of the proposed methodology (such as the implications of γ_i's changing as the base rate changes), studying the interrelationships between variables, and attempting to develop guidelines for the "engineering judgement" that is needed to set up each benefit estimation problem. None of these problem areas can be over emphasized in its importance. The data base problem includes the issue of what to do with unknown and unreported data. The methodology includes assumptions which need verification. The engineering judgement and variable interrelationship problems are also complicated.

1.5 SUMMARY AND CONCLUSION

The Accident Recovery Model (ARM) is a structured summary of the events and conditions which recreational boaters experience during and after boating accidents. The foregoing sections of this report show that ARM is very versatile and general, and yet highly applicable to specific problems. As demonstrated in the previous section, ARM can be used to generate quantitative estimates of the benefits associated with proposed or existing regulatory or educational programs. Another capability of ARM which has not yet been fully exploited is that of identifying the conditions under which a specified recovery problem occurs. For example, what are the conditions associated with PFD wear or non-wear? The answer will probably involve environmental conditions, the type of boat used, and characteristics of the boaters themselves.

It is instructive to consider the process of benefit estimation using ARM. At the outset, it should be noted that the ARM estimate is only as accurate as the inputs to ARM, and determining the inputs is far from a trivial problem. For example, ARM can estimate the benefit of increasing PFD wear to 50%, but the user must determine whether the regulatory or educational program he has in mind can produce a wear rate of 50%. The user must also specify how the program will affect wear rate. Does the program increase the proportion of people who wear PFDs routinely (i.e. the base rate) and/or does it increase the proportion of boaters who don PFDs when they encounter severe conditions? The answers to these questions will be different for each program and each problem area and will require a good deal of judgement. No exact procedures can be written to answer these questions. However, ARM itself can help by identifying the conditions and sub-population of boaters for whom the recovery problem is most severe. This is the second capability of ARM mentioned above. Wyle will attempt to develop general guidelines for answering these questions in later phases of the PFD research project.

Among the problems yet to tackle in the development of ARM, one of the most important is the problem of compensating for the limited data base. These accident reports (chiefly BARs) which provide enough information to be useful in ARM tend to be the most severe accidents, i.e. those involving a fatality or a considerable loss. Investigations by Marine Inspection Officers are often conducted only when a fatality is involved. Obviously,

many less severe boating accidents are not reported and/or not reportable. Some initial analysis conducted by Wyle for the Regulatory Effectiveness Project suggests that this problem may not be as serious as was first thought. However, further analysis of the problem is needed and is proceeding in the context of Regulatory Effectiveness.

A number of additions which should be made to ARM during subsequent phases of the project are already apparent. First and foremost, the data base must be enlarged to increase the accuracy of estimated benefits and allow more detailed analyses in areas where there is currently insufficient data. The form of the model should remain relatively fixed so that new data can be added to the existing base. In order to effectively use the expanded data base, the computer program must be modified to handle more complicated sorts involving larger numbers of variables, categories, and values. In addition, the benefit estimation methodology should be reviewed to identify problem areas and assumptions and assess their impact on the accuracy of estimated benefits. This review should also examine the feasibility of calculating confidence intervals for estimated benefits. Once this review is completed, the ARM program should be expanded to automatically calculate benefits and summarize relationships between ARM variables.

APPENDIX 1-A
ARM CODING INSTRUCTIONS
Explanation of Codes by Variable Number

2,3. Number of person coding or verifying.

4. Group - A number to indicate when coded.

5. Boat - Number of boat for this coder.

6. Victim - Number victims on each boat.

9. Jan = 01, Feb = 02, etc.

10. Code last two digits of year.

11. Use military designation (0-24 hrs).

15. 1 = Exclusive state, 2 = Joint

16. 1 = Collisions/groundings
2 = Swampings/capsizings/floodings/sinkings
3 = Fires and explosions
4 = Falls overboard
5 = Struck by boat or propeller
0 = Other

17. 1 = Open/manual (not canoe)
2 = Open/power
3 = Cabin motorboat
4 = Sail
5 = Canoe
6 = Houseboat
7 = Inflatable
0 = Other

18. 1 = Pleasure cruising
2 = Fishing
3 = Hunting
4 = Water skiing
5 = Skin diving or swimming (not underway)
0 = Other

19. 1 = River, creek, etc.
2 = Lake (other than GL), swamp, etc.
3 = Great Lake
4 = Coastal bay, inlet, sound, harbor, waterway, etc.
5 = Ocean

20. 1 = 0-5 yds
2 = 5-300 yds (1/6 mile)
3 = 300 yds (1/6 mile)-1/2 mile
4 = 1/2 mile-2 miles
5 = Greater than 2 miles

21. 1 = Boater from same boat
2 = Boater from another boat
3 = USCG
4 = CG Auxiliary
5 = State or local officials
6 = No one
7 = Other

23. 1 = Adult, 2 = Teenager (12-18),
3 = Child

27. 1 = Good health
2 = History of heart trouble or known to have occurred in this accident
0 = Other poor health

29, 31, 38. 1 = 0 - 2 min
2 = 2 - 5 min
3 = 5 - 15 min
4 = 1/4 - 1/2 hr
5 = 1/2 - 1 hr
6 = 1 - 1-1/2 hr
7 = 1-1/2 - 1 hr
8 = 2 - 3 hr
9 = 3 - 4 hr
10 = 4 - 5 hr
11 = 5 - 10 hr
12 = > 10 hr

39. 1 = Calm
2 = Choppy/Rough
3 = Swift Current

Note: For 1-digit variables:
8 = Unknown
9 = Not Applicable

For 2-digit variables:
88 = Unknown
99 = Not Applicable

ARM CODING INSTRUCTIONS (Continued)
ADDITIONAL NOTES

1. Be sure to right-justify all codes.
2. ARM Coding Group = 1 for this sample
3. The following variables should never be coded "unknown:"

   25 - Level Flotation Boat - if not mentioned, code "no" (2)

   26 - Victim's Condition - if there is no evidence of ill health or injury during the accident, use the "not seriously injured" branch.

   27 - Health - if not mentioned, code "good health" (1)

   36 - Distress Notification - if no information to the contrary is available, code "no special means..." (7)

4. Variables: 33 - PFD type

   34 - PFD malfunction

   and 35 - Improper PFD use should be coded "not applicable" (9) if the victim did not use a PFD. Variable 35 should be coded "no" if the victim held onto the PFD in the water.

5. In most cases, the coder should presume the following:

   28 Victim's Behavior and Circumstances

   (a) that the victim remained in the water (22) if the available information does not indicate that he re-entered the boat.

   (b) that the victim "fell or was thrown out, etc." (10) or "abandoned boat due to fire, etc." (3) if it is not mentioned that he swam for shore, or another source of flotation and is known to have been separated from boat.

   30 PFD Availability and Use

   (a) "Took PFD off after accident" (11) refers only to voluntary acts. If the victim slipped out of the PFD, or the PFD was torn off him, the case should be coded as "Did not take PFD off" (1).

ARM CODING INSTRUCTIONS (continued)

CODES FOR VARIABLE 8 - STATE

Alaska	02	Missouri	29
Alabama	01	Montana	30
Arizona	04	Nebraska	31
Arkansas	05	Nevada	32
California	06	New Hampshire	33
Colorado	08	New Jersey	34
Connecticut	09	New Mexico	35
Delaware	10	New York	36
Dist. of Columbia	11	North Carolina	37
Florida	12	North Dakota	38
Georgia	13	Ohio	39
Hawaii	15	Oklahoma	40
Idaho	16	Oregon	41
Illinois	17	Pennsylvania	42
Indiana	18	Rhode Island	44
Iowa	19	South Carolina	45
Kansas	20	South Dakota	46
Kentucky	21	Tennessee	47
Louisiana	22	Texas	48
Maine	23	Utah	49
Maryland	24	Vermont	50
Massachusetts	25	Virginia	51
Michigan	26	Washington	53
Minnesota	27	West Virginia	54
Mississippi	28	Wisconsin	55
		Wyoming	56

VARIABLES 2,3 — CODERS AND THEIR CODE NUMBERS

01	Steve Bremmer
02	Dave Johnson
03	Ted Doll
04	Steve Cohen
05	Chris Stiehl
06	Donna Day
07	Gayle Lancaster
08	Bobby Clements
09	Bob Douglas

ARM CODING INSTRUCTIONS (concluded)
ADDITIONAL NOTES

1. Variable 36 - Distress Notification — If a highly noticeable collision, capsizing, etc. served as a form of distress notification, the code should be "no special means" (7).

2. Variable 24 - Final Boat Configuration — For boats which were swamped, capsized, or flooded, presume that the boat was not level unless stated otherwise.

3. Variable 38 - Time in the Water — Code the total time the victim spent in the water until he was rescued or died.

4. Variable 29 - Time in or With Boat — If a victim exited and re-entered the boat several times, time in or with boat is the sume of these separate times.

5. Variable 24 - Final Boat Configuration — "Propelled" means actually underway, not propellable.

6. Variable 13 - Number of People on Board — For accidents involving a person in the act of water skiing, code only the skiier, but list the number of people on board as the total people on board the boat plus skis.

   When the accident type is "struck by boat or propeller" and the person struck was not a passenger on a boat, code the No. POB as not applicable (99).

7. Variable 26 - Victim's Condition — Adequate emergency treatment means that which could be administered by a graduate of the standard short courses given by the Red Cross.

2.0 SUDDEN DROWNINGS

2.1 INTRODUCTION

Approximately 6500 people drown in the United States each year [1,2] and about 10 out of 11 boating deaths each year are due to drowning [3,4]. Many of these drowning victims die very quickly, within a few minutes of entering the water and despite good swimming ability. Occasionally, the victim enters the water willfully and simply disappears. The purpose of this subtask is to account for these victims, and determine what countermeasures are possible. For the purposes of this investigation, a sudden drowning will be defined as any drowning which occurred within five minutes after the person entered the water and which cannot be accounted for solely by the fact that the person was unconscious or a non-swimmer.

2.2 DATA ACQUISITION

Data have been gathered from several sources:

1) Biomedical, human factors, and psychological literature; and news reports
2) Wyle in-depth accident investigations, MIO reports, and BARs
3) Near sudden drowning victims and first-hand accounts of witnesses.

Data have been acquired from research and news journals, professionals (doctors, swim coaches, researchers, etc.), and accident reports and investigations. During Phase I of this project, all BARs from 1969 to 1973 were screened to generate data concerning sudden drowning victims. The following two pages (Figure 2-1) are the data collection sheets for the screening of BARs. Of course, many of these questions were relevant to other tasks. For example, Question 9 was included for the benefit of the subtasks dealing with PFD availability and PFD use. In Phase II additional data will be gathered from in-depth sudden drownings investigations.

---

[1] Iskrant, A.P. and Joliet, P.V., Accidents and Homicide, Harvard University Press, Cambridge, 1968.

[2] Press, E., Walker, J. and Crawford, I., "An Interstate Drowning Study," American Journal of Public Health, Vol. 58, No. 12, December 1968, 2275-2289.

[3] Diety, P.E. and Baker, S.P., "Drowning, Epidemiology and Prevention," American Journal of Public Health, Vol. 64, No. 4, April 1974, 303-312.

[4] USCG, Boating Statistics 1974, CG-357, 15.

SUDDEN DROWNINGS: VICTIM SEARCH

Screen for:

- Someone must die
- He/She must drown
- Be a swimmer (one who can dog paddle is a "swimmer")
- Must be conscious

Accident and/or BAR Nos. ____________ Accident ____________ BAR

1. What type of accident was it? ______________________________________

   ____

2. Water temperature ________ ____ Unknown Date ________________

   Air temperature ________ ____ Unknown

   Time of day ________ ____ Unknown

3. Location (in U.S.) and type of body of water ________________

   Boat Type ______________________________________

4. Anything known about exposure to cold? ________________

   Sudden environmental change? ________________

   Sun? ______________________________________

   Alcohol? ______________________________________

5. Anything known about the victim's physical condition (heart trouble, athlete, etc.)?

   ____

   ____

6. Victim's age ________ ____ Unknown

   Sex ________ ____ Unknown

   Weight ________ ____ Unknown

   Height ________ ____ Unknown

FIGURE 2-1. DATA ACQUISITION FORM

7. Any shock-producing stimuli (injury, trauma, fear, etc.)? ____________________

____

____

8. Describe what happened, briefly ____

____

____

____

9.* Were adequate PFD's available on this boat? _____Yes _____No _____Unknown

10.* Was any information available on alcohol? If no, leave blank; if yes, then what?

____

____

11. Did this victim have a PFD? _____Yes _____No _____Unknown

* Fill in for first victim of this accident, but apply the question to the whole accident report.

FIGURE 2-1. DATA ACQUISITION FORM (concluded)

Other professionals interested in the problem of sudden drownings have been contacted by Wyle personnel. In the Phase II effort of the PFD research project, Dr. Keatinge and his associates will be visited in London. He is a world-reknowned expert in the fields of drowning and hypothermia. He has published research suggesting that under certain conditions there is a breakdown in the body's thermoregulatory capacity leading to a very rapid drop in body core temperature (hypothermia). Also, he suggests that a respiratory reflex when immersed in cold water combined with the higher viscosity of very cold water may lead to rapid exhaustion and drowning.

Capabilities have been established for collection of data from near victims and first-hand accounts of witnesses. There are two sources of in-depth information. First, data will be acquired through an association with Dr. John Aycock, M.D., of Gainesville, Georgia, and Mr. Peter Kennedy (college swim coach). Dr. Aycock treats a number of sudden drowning victims each year and is willing to cooperate with us in gathering data on victims, near victims, and accident sites. Mr. Kennedy is the swimming coach at Brenau College in Gainesville. Both of these gentlemen have for some time been interested in sudden drownings and the body's reaction to cold water. They will collect a variety of detailed data concerning drowning victims and near victims of Lake Lanier. They will collect data on the water, weather, behavior, life style, stressors, body build, medical and physical history, and eating patterns of the individuals. These data will be sent to Wyle for analysis.

The second source of in-depth information is the accident investigations performed by the National Park Service at Lake Mead. Preliminary contact has been made with the rangers there and they have indicated a willingness to participate. Wyle personnel will visit Lake Mead under Phase II to set up a data collection system.

The data collection form for the in-depth studies (Lake Lanier, Ga. and Lake Mead) is shown in Figure 2-2. The depth of the investigation is obvious from the extent of information requested on the form. It is hoped that the in-depth data from these investigations will further help to identify the causes of and circumstances surrounding sudden drownings.

AD-A037 221 WYLE LABS HUNTSVILLE ALA F/G 6/7

PERSONAL FLOTATION DEVICES RESEARCH. PHASE I.(U)

JUL 76 T DOLL, C STIEHL, M PFAUTH, R MACNEILL DOT-CG-42333-A

UNCLASSIFIED MSR-76-43 USCG-D-3-77 NL

2 OF 4

AD

A037221

1. Type of Accident. Was this a ☐ boating accident, ☐ swimming accident, or ☐ other (specify ____________________)?

2. Time of day of the incident ______________. Date ______________

Time when these observations were recorded ____________________

Date and time of death if different from above ____________________
(If victim did not die, write "near victim".)

3. Weather Data: Local map of area should be attached, including a map of water temperatures, if possible.

What was air temperature in the area? ______ °F

What was water temperature in immediate area? ______ °F

What was the humidity? ______ %

Wind? ____________________

General description of weather: ____________________

____

____

4. Personal Data: Did the person know how to swim? ☐ Yes ☐ No ☐ Unknown

Age of Victim: ________ Sex: ☐ Male ☐ Female

Height: ____________ Weight: ____________

Body temperature (if appropriate) and how measured ________

____

BAC/drugs (if known) ____________________

____

General body build/condition and description ____________

____

____

____

FIGURE 2-2. SUDDEN DROWNING INVESTIGATIONS DATA FORM

Physiological data to collect IMMEDIATELY AFTER accident and SEVERAL HOURS LATER (assuming victim lives):

a) Pulse: ____________________

b) Blood Pressure: Systolic __________ Diastolic __________

c) Respiration: Shallow __________ Deep __________

Rapid ________ Normal ________ Slow ______

d) Describe general appearance and condition of victim, e.g. note if victim appears flushed or pale, if victim is coughing, tense, or relaxed, etc. ____________________

____

____

____

____

5. Medical History (include any pertinent facts, such as diabetes, heart trouble, physical ailments, etc.)

FIGURE 2-2. SUDDEN DROWNING INVESTIGATIONS DATA FORM (Continued)

6. <u>Personal History</u>: What kind of person, lifestyle; did the person often take risks, overexert?

7. <u>Accident History, Preaccident</u>: What had the person been doing and eating for 24 hours previous to the accident? ______________________________

____

____

____

8. <u>Accident History, Accident</u>: What was the person doing immediately prior to the accident? ______________________________

____

____

____

____

FIGURE 2-2. SUDDEN DROWNING INVESTIGATIONS DATA FORM (Continued)

99

Any fatigue present? ______

______

______

Exposure to other stressors (glare, shock/vibration, unexpected immersion, alcohol—what type, heat, dehydration, etc). List and explain. ______

______

______

______

______

______

Any stress-producing stimuli? ______

______

______

9. Interviews: We should interview, if possible, family, friends, and particularly witnesses of the incidents. If the victim survives, we should note his verbal responses as he recovers and interview him when recovered. Questions should follow any pertinent line of investigation. They should include, but not be limited to, questions concerning what happened, what do people remember about how it happened; anything that they can remember from the time of the accident or just prior could be important. What did the victim say, feel, and do, etc? Attach additional sheets if necessary. Include questions and answers. If you have a cassette tape recorder available, use that and send the tapes, Wyle will transcribe them. Be sure to identify whom you're talking to and their involvement.

Names, addresses and telephone numbers of witnesses:

1. ______

2. ______

3. ______

4. ______

Obtain independent narratives of accident from each of several witnesses.

FIGURE 2-2. SUDDEN DROWNING INVESTIGATIONS DATA FORM (Continued)

10. How was the victim rescued/body recovered? By Whom?

____

____

____

FIGURE 2-2. SUDDEN DROWNING INVESTIGATIONS DATA FORM (Concluded)

2.3 RESULTS

2.3.1 Literature Review

The literature review has tended to confirm the position taken in earlier interim reports: the two primary causes of sudden drownings appear to be reactions to sudden cold, and cardiac failure, with alcohol being a possible contributory factor in many cases. Recent research [3,5,6] has shown that a large number (perhaps as high as 50%) of drowning victims have ingested alcohol. Alcohol consumption results in vasodilatation which can contribute to cardiac insufficiency and leads to accelerated heat loss in cold water[6,11].

Although the symptoms of cardiac failure and reaction to sudden cold are difficult to distinguish, most authors apparently prefer to discuss sudden drownings in terms of reactions to sudden immersion in "cold" water (where "cold" is relative to body temperature; e.g., 73°F (23°C) or less). One author describes a series of effects that may result from sudden immersion: changes in blood volume and cario-vascular function, changes in vascular smooth muscle function, facilitating heat loss, and sometimes reflex hyperpinoea - leading to hyperventilation or gasping, and incoordinant muscular activity[7]. Hyperventilation could in some cases lead to inhalation of water which could cause laryngospasm, resulting in drowning.

In almost every source in the literature, the subject of hypothermia or reaction to sudden cold arises. To be sure, the authors do not claim hypothermia as "the cause" of death, but rather as a significant contributor to death. Research indicates that at water temperatures of 73°F (23°C) or lower, the human body loses heat more rapidly than it produces it[8,9]. Thus, there

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[5] Stiehl, C.C., Alcohol and Pleasure Boat Operators, Report to USCG for contract DOT-CG-40672-A, June, 1975. NTIS No. AD A014 095.

[6] Plueckhahn, V.D., "The Aetiology of 134 Deaths Due to 'Drowning' in Geelong During the Years 1957 to 1971," The Medical Journal of Australia, November 18, 1972, 1183-1187.

[7] Ritchie, R.C., "The Physiology of Drowning," The Medical Journal of Australia, November 18, 1972, 1187-1189.

[8] "Hypothermia, Fighting An Ever Present Killer," The Ensign, August, 1975, 42-43.

[9] "About Life Jackets 'N PFD's With EHP," Stearns Manufacturing Company, 1975.

is some effect of cold water in almost every drowning, since most drownings occur in water of $73^{\circ}F$ ($23^{\circ}C$) or less. Dr. Keatinge has indicated that under centain conditions sudden drowning victims may not be able to properly regulate their body temperature, and may suffer hypothermia in less time than might be expected from classical hypothermia studies.[10] This possibility will be investigated in Phase II research.

Some authors believe that sudden immersion in cold water triggers the release of a histamine-like substance in some individuals that causes unconsciousness. Keatinge[11] has reviewed some cases which may fit in this category.

> "These cases are usually poorly documented, but occassional accounts show that good swimmers have jumped or dived into water and have floated to the surface, dead, within a minute or two." Page 9.

These individuals may possess a muscular or skinny body build, leading to quick chilling of the body surface and promoting heat transfer. The data from both Keatinge and Press/Walker tend to support this idea, although they are not conclusive. As Press and Walker[2] report,

> "This contrast could be interpreted to mean that the good swimmer is more vulnerable to cold water." Page 2287.

> "Further information is needed on the many relatively unexplained instances where persons in apparent good health and good physical condition succumb to 'fatigue,' 'panic,' 'cramps,' and the like. A continued analysis of the role that hypothermia...plays in these cases should be pursued." Page 2288.

Keatinge's analysis of the problem follows similar logic. He states that, "... although simple hypothermia cannot account for these deaths, cold does appear to play a part in them." (p. 8). The problem, as he sees it, is to determine "what reflex or direct effects of cold can cause a good swimmer to drown while attempting to cover... a short distance." (P. 9). He refutes the explanation that a jet of water in the nose causes cardiac arrest. "... there is no evidence of this causing complete arrest of the heart for anywhere near the 5 - 15 minutes that would be necessary to cause death." (pp. 9 - 10). He concludes by suggesting that sudden cooling of the skin could cause reflexes which result in cardiac failure.

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[10] Personal communication from W. R. Keatinge to T. Doll.

[11] Keatinge, W. R., Survival in Cold Water, Oxford University Press, 1969.

All of the authors quoted above are pointing toward a sudden cold/cardiac failure state of the individual as a cause of sudden drownings. This state leads to disorientation, confusion, dizziness, fainting, sleepiness, and disinterest. Obviously, this state is not optimal when in water. The onset of this state can be delayed. Sudden cold may be due to a pocket of cold water that is encountered, as well as cold water in general. Dr. Aycock has evidence of temperature variability on fresh water surfaces. The vulnerability of the individual to these conditions has also been described as extremely variable. One recent study has suggested that cognitive functioning may not be as impaired as first believed, if the subject is well-motivated.[12] Subjects in this study were subjected to a mean drop in rectal temperature of 1.3°F (0.44°C) and showed no decrement in reasoning, vigilance performance, or memory. However, some sudden drowning and moderate exposure (1-1/2 hours, 59°F (15°C) water) victims have shown rectal temperatures below 97°F (36°C), correlating with Keatinge's concept of inability to regulate body temperature, so this study may not have adequately measured cold water effects.

The conclusion of the literature review is that sudden drownings are caused by a combination of factors, such as sudden cold, cardiac failure, and possibly alcohol. The data from sudden drowning victims will indicate how often these factors are known to be present.

2.3.2 Boating Accident Screening

All of the BARs for 1969 and 1973 were screened for potential sudden drowning victims. Basically, they were screened for victims who: 1) drowned quickly (in five minutes or less if time in the water was known), 2) could swim, and 3) were conscious upon entering the water. For each case that survived the screening, the complete BAR was read to determine if any victims were possible sudden drownings (some probability > 0), probable (probability > 0.50), or very likely (probability > 0.90). For each of these victims, the data acquisition form (Figure 2-1) was completed. Victims whose condition gradually worsened throughout the accident; were injured, burned, or unconscious; or suffered from classical (slow) hypothermia, fatigue, or exhaustion after entering the water were not included in the sudden drownings data. The time in the water before drowning was rarely known, but when it was, the victim had to have died within about five minutes of entering the water.

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12 Baddeley, A.D., W. J. Cuccaro, G. H. Eastrom, G. Wetman, and M. A. Willis, "Cognitive Efficiency of Divers Working in Cold Water," Human Factors, 17(5), 1975, 446-454.

TABLE 2-1. NO. OF SUDDEN DROWNING VICTIMS BY TYPE OF ACCIDENT, BODY OF WATER, BOAT TYPE

	Joint Jurisdiction BARs 1969 and 1973	State Jurisdiction BARs - 1972-1974	Total
A. Type of Accident			
Collisions	5	0	5
Capsizings	43	6	49
Fires/Explosions	1	0	1
Falls Overboard	44	4	48
Other	25	1	26
B. Type of Body of Water			
Lake	24	10	34
Creek/River	31	1	32
Canal/Channel	2	0	2
Bay/Basin/Bayou/ Ocean/Sound	22	0	22
Unknown	39	0	39
C. Boat Type			
Runabout	18	2	20
Cabin Cruiser	16	0	16
Bass Boat	2	0	2
Johnboat/ Sm. Open Boat	67	5	72
Sailboat	3	1	4
High Performance/ Jet/Ski Boat	0	0	0
Pontoon/Houseboat	0	0	0
Other	12	3	15

FIGURE 2-3. NUMBER OF SUDDEN DROWNINGS BY STATE (WITHIN THE SAMPLE)

All joint jurisdiction BARs from 1969 and 1973 were screened, along with approximately 30 state jurisdiction BARs. The selection process reduced these to 49 possible sudden drownings, 54 probable, and 26 that were almost certainly sudden drowning victims. Thus, 129 potential sudden drowning victims were used as a data base for the analysis that follows.

In terms of type of accident, type of body of water, and boat type, Table 2-1 shows the data broken down for each category. These are in terms of number of victims for each subgroup. Figure 2-3 shows the distribution of sudden drowning victims by state.

It is not surprising that capsizings and falls overboard account for about 75% of the sudden drownings. However, well over half of the sudden drownings involved johnboats or small open boats. This fact is significant in terms of the type of activity the individual engages in and the type of individual that is likely to be a sudden drowning victim.

The people-oriented data are listed in Table 2-2. As can be seen from the table, not much is known about the victims, other than the fact that they are almost all males. For the few victims whose health was described, slightly over 75% were described as in good health, while 16% had heart trouble (that was reported) before or during the accident. Fatigue or fatiguing activities prior to the accident were not reported in any accident reports. In general, not much is known about the individual victims.

TABLE 2-2. SUDDEN DROWNINGS/PEOPLE-ORIENTED DATA

		Joint Jurisdiction 1969 and 1973	State 1972 - 1974	Total
A. Physical Condition of Victim	General Good Health	27	11	38
	Known Heart Trouble	8	0	8
	Known to Have Been Fatigued . .	0	0	0
	Unknown	79	0	79
	Other	4	0	4

TABLE 2-2. SUDDEN DROWNINGS/PEOPLE-ORIENTED DATA (concluded)

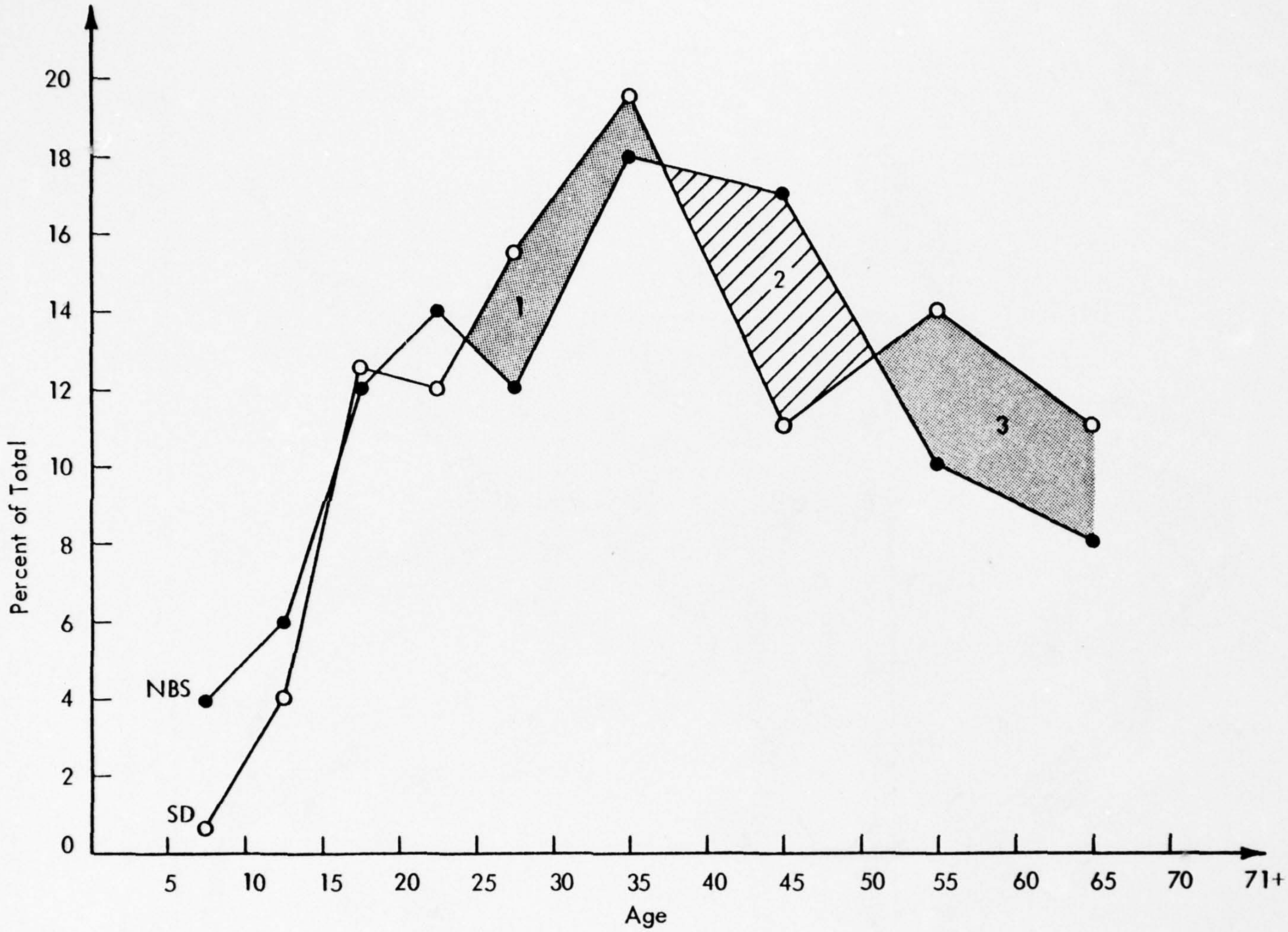
		Joint Jurisdiction 1969 and 1973	State 1972 - 1974	Total
B. Height	Unknown	116	8	124
	5'8" to 6'0"	1	2	3
	6'0" to 6'4"	1	1	2
C. Weight	Unknown	116	8	124
	176-200 lbs	1	3	4
	> 200 lbs	1	0	1
D. Sex	Male	112	10	122
	Female	6	1	7

The ages of the victims are shown in Figure 2-4. The figure shows the ages of sudden drowning victims as compared to the general boating population (from NBS[13]).. Regions 1 and 3 on the graph show ages where the risk of a sudden drowning is high. Region 2 corresponds to ages where the probability of a sudden drowning is low. These age groups may correspond to the types of boats owned. The ages corresponding to Regions 1 and 3 may be more likely to own small open boats, while those in Region 2 may be more likely to own larger, family boats.

The dates of the accidents and the time of day distribution are shown in Figures 2-5 and 2-6, respectively. These data are graphed with the same data as reported for all accidents in CG-357 for 1969. As can be seen in Figure 2-5, there is a tendency for sudden drownings to occur more often during the cooler months, although the peak incidence rate is in mid-summer.

Figure 2-6 illustrates the tendency for sudden drownings to occur much more often in the morning than other accidents. This may correspond to the times that small open boats are typically used. The morning hours also correspond to cooler water temperatures, particularly in shallow waters.

[13] USCG, Recreational Boating in the Continental United States in 1973: The Nationwide Boating Survey, Office of Boating Safety, October, 1974. NTIS No.. AD A000 471.



SD	6-10	11-15	16-20	21-25	26-30	31-40	41-50	51-60	61+
NBS	0-12	12-15	16-19	20-25					

SD = Age by percent of total for sudden drownings victims.
NBS = Age by percent of total for boaters in general (Nationwide Boating Survey).

FIGURE 2-4. SUDDEN DROWNING VICTIMS AND BOATERS BY AGE

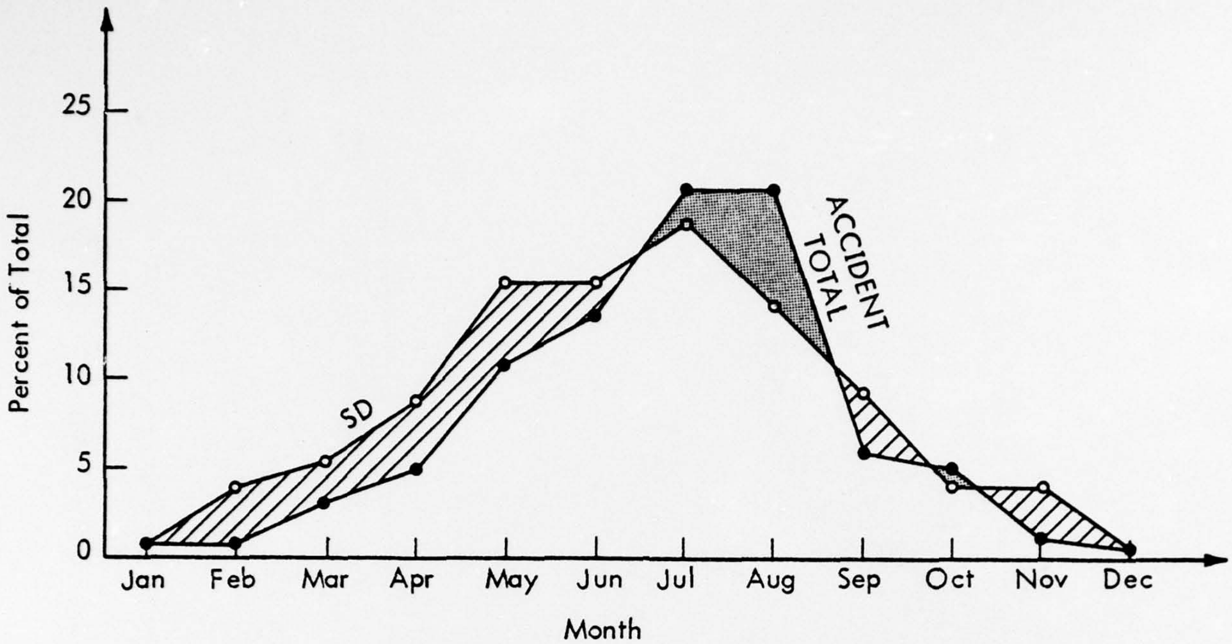


FIGURE 2-5. TOTAL SUDDEN DROWNINGS AND 1969 ACCIDENTS BY MONTH

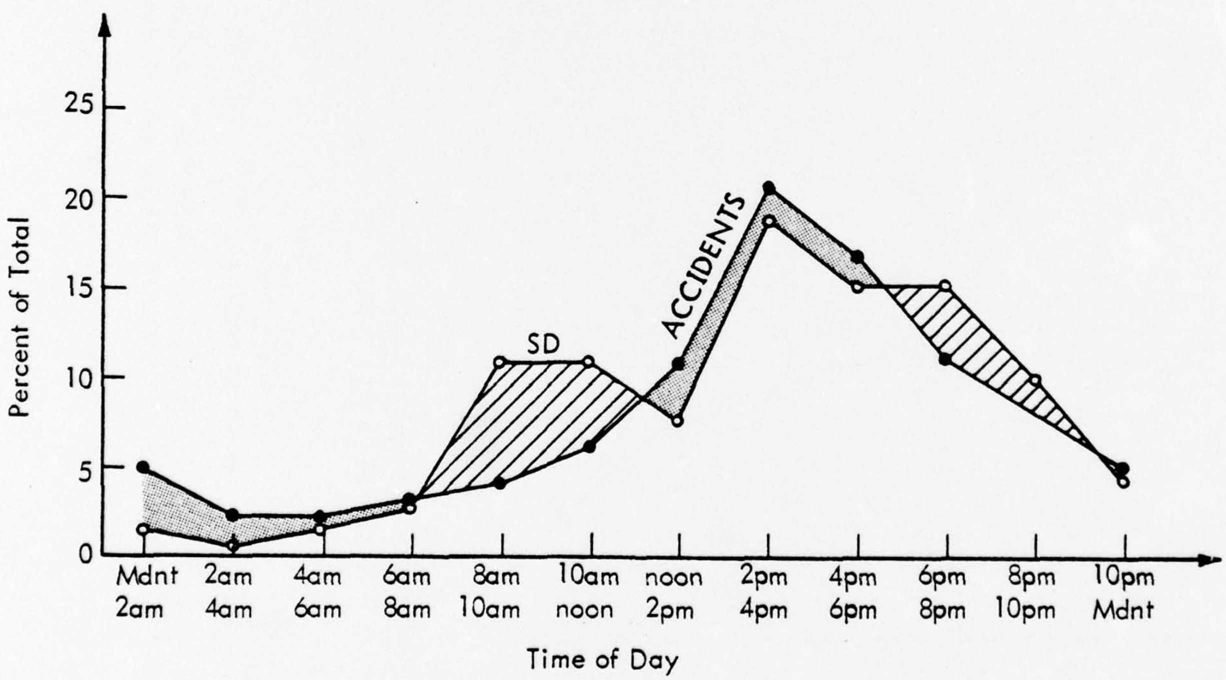


FIGURE 2-6. TOTAL SUDDEN DROWNINGS AND 1969 ACCIDENTS BY TIME OF DAY

NOTE: Thirty-eight unknowns not included.

The air and water temperatures for the sudden drowning victims are shown in Figure 2-7. Of course, the mean of the water temperatures is less than the mean of the air temperatures. More significant is the fact that virtually all of the water temperatures are below 73°F (23°C) (the point at which an average person's body cannot produce more heat than it loses when immersed). In fact, over 45% of the sudden drownings took place in water below 60°F (16°C).

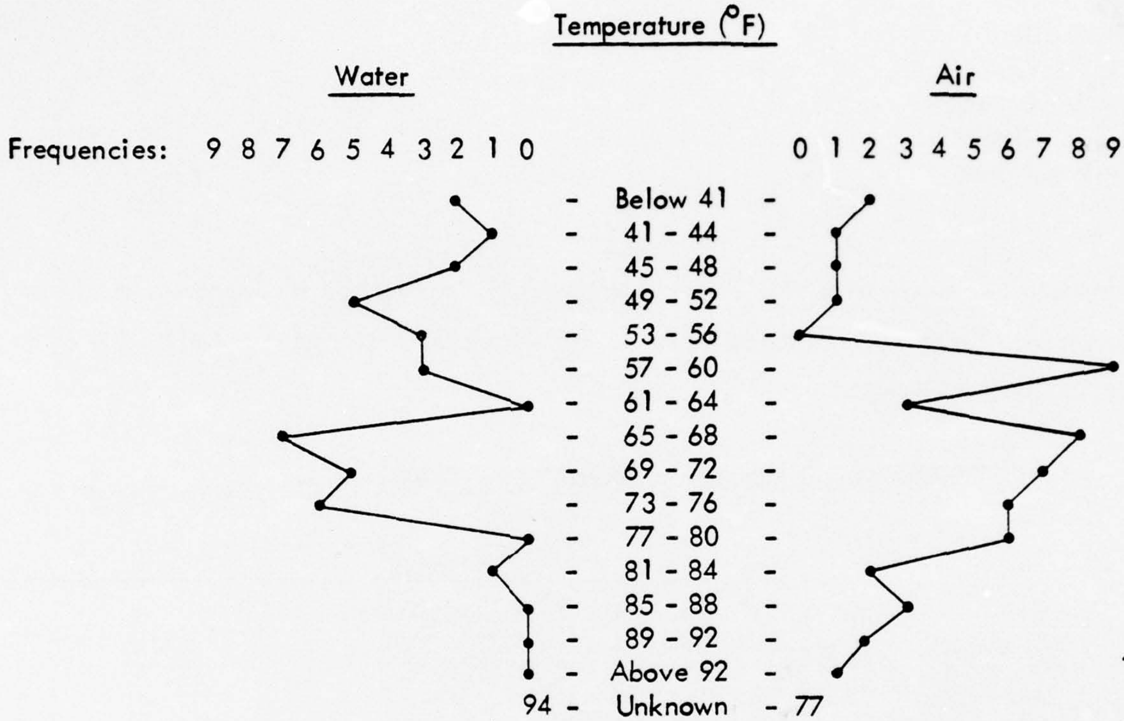


FIGURE 2-7. AIR AND WATER TEMPERATURES FOR SUDDEN DROWNING VICTIMS

Stress producing stimuli (those which may have precipitated a cardiac problem) were noted when they were known. Sudden immersion was listed as a stress producing stimulus when the victim did not enter the water of his own free will and no other such stimulus was apparent. Occasionally, a victim was exposed to more than one potential stress-producing stimulus. When a stimulus other than sudden immersion was present, it was considered primary. The results are listed in Table 2-3. The results show sudden immersion to be the leading potential stress-producing stimulus.

TABLE 2-3. STRESS PRODUCING STIMULI

Primary Stimulus	Frequency: Joint Jurisdiction BARs 1969 and 1973	Frequency: State Jurisdiction 1972 - 1974	Total
Sudden Immersion	71	10	81
Collision	5	0	5
Fire/Explosion	1	0	1
Sinking (fear, etc., caused by sinking)	6	0	6
Other (including witnessing a death)	21	1	22
Unknown	28	0	28

The information that was available concerning the victim's ingestion of alcohol (if any) was also recorded. These data are listed in Table 2-4. They indicate that at least 13.2% of the victims had been drinking.

TABLE 2-4. SUDDEN DROWNINGS AND ALCOHOL

Victim's Alcohol Ingestion	Frequency: Joint Jurisdiction BARs 1969 and 1973	Frequency: State Jurisdiction 1972 - 1974	Total
Drunk: According to witness	3	0	3
Drunk: According to BAC	1	0	1
Had been drinking (extent unknown)	9	2	11
Known drinker; drinking very probable	2	0	2
Unknown (alcohol usually not mentioned)	103	9	112

In most cases, alcohol was not mentioned. In several cases, alcohol may have been involved, but witnesses were reluctant to discuss it. However, it was known, or, at least highly probable, that the victim had been drinking in 13.2% of the cases. This is a significant number which is certain to underestimate the magnitude of the alcohol problem, since so many cases were listed under "unknown."

A previous study on balance[7] indicated that stressor effects (due to alcohol, fatigue, rough water) caused significant decrements in balancing performance on small craft. Thus, fatigue, alcohol, and rough water can lead to falls overboard, and the same factors can contribute to sudden drownings.

Finally, the PFD information available was tabulated. These questions are listed in Table 2-5. Although the majority of the boats had an adequate number of PFDs, they were often not used. This may be due to the fact that so many of the accidents were capsizings or falls overboard — which may have occurred too quickly to have allowed access or use of PFDs. An overwhelming number of the sudden drowning victims did not use a PFD. However, in 9% of the known cases the victim was in contact with a PFD and lost it or discarded it. In a similar study[2], it was found that less than 10% of those who drowned in boating accidents in 1966 used PFDs. The figure of 11% (14/123) derived from Table 2-5 is in close agreement with this. Thus, it appears one cannot conclude that sudden drowning victims are more or less likely to have used PFDs than other drowning victims ($\chi^2 = 0.85$, df = 1, $p > 0.25$).

TABLE 2-5. SUDDEN DROWNINGS AND PFDs

A.	Was an adequate number of PFDs on board?	69	Yes
		32	No
		28	Unknown
B.	Were they used?	35	Yes
		61	No
		24	Not Applicable
		9	Unknown
C.	Did this victim have or use a PFD?	3	Yes - Kept it (held or worn)
		11	Yes - Lost it/Let go/Slipped out
		109	No
		6	Unknown

From the review of these sudden drowning BARs, several key factors can be extracted:

- Approximately 10% of all boating fatalities are sudden drownings.

[7] Stiehl, C. C., Safe Loading Operator Task: Balance Study, Wyle Laboratories Marine Technology Staff Technical Brief 76-06, February, 1976.

- Over 55% of the sudden drownings were associated with johnboats or small open boats.
- Over 75% of the sudden drownings involved capsizing or fall overboard accidents.
- The victims were almost exclusively males, and generally in good health.
- Sudden drowning victims were often between 26 and 40, or over 50 years old.
- Sudden drownings tend to occur in colder weather more than other accidents and earlier in the day (morning hours), although the peak hours and months for sudden drownings are the same as those for other accidents.
- Over 45% of the known sudden drownings took place in water below 60°F (16°C).
- Sudden immersion was frequently present as a potential stress-producing stimulus.
- Alcohol may have been a factor in over 13% of the sudden drownings.
- Sudden drowning victims apparently are no more or less likely to have been wearing a PFD than other drowning victims.

2.3.3 ARM Results: Sudden Drownings

The ARM data provide several indications concerning the magnitude of the sudden drownings problem and the causes. ARM projects that 2100 out of an estimated 17,206 people involved in boating accidents yearly suffered some type of debilitating injury or condition during the accident. Less than 0.5% of the victims are known to have had poor health before the accident. There are some indications in the ARM data that the probability of recovery is lower at colder water temperatures. However, the water temperature recovery data are variable and there are a lot of victims for whom the water temperatures were unknown. There are nearly 900 victims per year (5% of the total number of people involved in boating accidents yearly) who die in the first fifteen nimutes after an accident, and the probability of recovery for PFD wearers is more than 4% higher in the first fifteen minutes than for non-wearers. In fact, the first few minutes is the time category where the difference in probability of recovery for PFD wear as opposed to non-wear is greatest. Thus, the ARM data tend to confirm that sudden drownings are potentially a great problem, that many people die soon after the accident, and that the chance of survival is greater when wearing a PFD.

2.4 CONCLUSIONS AND COUNTERMEASURES

The conclusions of Sections 2.3.1 and 2.3.2 tend to support each other. In fact, there is evidence in favor of the sudden cold/cardiac failure explanation. Potential stress producing stimuli were present in almost every case, and often the victim was exposed to more than one. The water temperatures were invariably below 73°F (23°C) and often below 60°F (16°C), suggesting sudden cold as a factor. Cardiac failure (including any malfunction or insufficiency) was present in 16% of the known cases. All of these factors were sometimes accompanied by alcohol, which sometimes magnifies the resulting ill effects. Indeed, it was a rare victim who did not suffer from more than one of these factors simultaneously.

Since the potential causes result from similar situations and lead to very similar ill effects or symptoms, countermeasures may be directed at these situations and symptoms rather than at individual causes. For example, keeping the boater partially out of the water would: 1) reduce exposure to the effects of sudden cold, and 2) thereby lower the probability of laryngospasm or cardiac failure. This could be accomplished through increased PFD wear, increased johnboat stability, or level flotation. The fact that 2% of the victims died wearing a PFD, while an additional 9% had access to one, but lost it, suggests that increasing accessibility alone may not have as dramatic an effect on sudden drownings as increasing the wear rate for PFDs. This concept is supported by the benefit estimation procedures from ARM (see Section 1.4).

Of course, if everyone wore a wet suit, the sudden cold problem would be greatly diminished, but this is not practical, because they are expensive and uncomfortable in warm weather. The most effective means of reducing deaths due to sudden drownings would be to reduce capsizings and falls overboard, particularly in small craft, and increase PFD wear. If the effects of sudden cold are better defined in the future, through research such as Keatinge's, it is possible that PFDs could be designed to help counteract these effects.

The boating public may respond to educational efforts aimed at reducing the frequency of sudden drownings. Such education should stress:

- The frequency of sudden drownings.

- The fact that there is no "cure" other than prevention; i.e., the accidents happen so quickly that only pre-accident caution is effective in saving sudden drowning victims.
- The dangers of excessive drinking, fatigue, cold water, and unstable craft.

The factors of cardiac insufficiency and reaction to sudden immersion/sudden cold, along with possible confounding factors of alcohol and fatigue have been suggested as important in sudden drownings. The literature review, accident data, and ARM data do not contradict these suggestions, but tend to support them. Hopefully, the data from in-depth investigations of sudden drowning victims and near victims and the contact with Dr. Keatinge, will add more evidence in support of these ideas. Figure 2-8 presents the workflow diagram for sudden drownings research with the asterisks (**) indicating the area of concentration for future work.

Psychological, Human Factors, And Medical Literature Review re:
1. Reactions to Sudden Environmental Changes
2. Causes of Stress, Drownings

↓

Study of Wyle In-Depth Accident Investigations And BAR's re:
1. Frequency of Sudden Drownings
2. Conditions Surrounding Sudden Drownings

↓

Analyses of Accident Data And Comparisons With Literature. Tentative Cause List Developed: Stress, Sudden Cold, Cardio-Vascular Insufficiency

↓

** Collection of Detailed Data Concerning Sudden Drowning Victims And Near Victims: Medical History, Background, Behavior, Environment, Physical Makeup: through Dr. Aycock, Lake Mead, and Dr. Keatinge

FIGURE 2-8. WORKFLOW FOR SUDDEN DROWNINGS RESEARCH

3.0 THE LIFE-SAVING INDEX

Coast Guard statistics[1] show that between 1400 and 1800 people die in recreational boating accidents each year. The same source also reports that approximately 90% of these deaths are due to drowning. In order to reduce the number of drownings, the Coast Guard has promulgated PFD standards and carriage requirements and undertaken research concerning the use and functioning of PFDs. The present report represents the first part of this research undertaken by Wyle Laboratories. Previous work by other contractors indicated that it might be beneficial to develop a "life-saving index" (LSI). The LSI is a quantitative estimate of a PFD's life-saving capability.

The life-saving index of a PFD has been defined as the product of its physical effectiveness, reliability and wearability[2].

$$LSI = I_E \times I_R \times I_W$$

where:

I_E	=	Physical effectiveness; the probability that the PFD maintains the wearer in a position which permits continuous breathing
I_R	=	Reliability; the probability that the PFD performs as designed
I_W	=	Wearability; the probability that the PFD is worn by the victim when he enters the water in a marine accident.

The LSI is being developed in order to provide the Coast Guard with a more flexible and effective regulatory mechanism for approving PFDs. One of the chief reasons for revising the PFD approval process is to stimulate manufacturers to develop innovative PFD designs with a higher overall life-saving capability. The existing PFD approval process uses measures related only to PFD effectiveness and reliability. These parameters are reasonably high for

[1] United States Coast Guard, Boating Statistics 1974, CG-357.

[2] Greenhouse, L., Kerne, B. and Weiers, D., A Reliability Investigation of Personal Flotation Devices, Phase I, Operations Research, Inc., CG-D-13-74, 1973. NTIS No. AD-770-210.

most PFDs. However, the wearability of currently approved PFDs is low. Studies conducted by Wyle show that only 7% of the boating population routinely wears a PFD[3]. The low rate of wear seriously hinders the overall life-saving capability of PFDs. The development of better PFD designs may of necessity involve a trade-off between PFD reliability, effectiveness, and wearability. For example, some new PFD designs might have slightly lower reliability or effectiveness but much higher wearability. The LSI will enable the Coast Guard to evaluate whether slight decreases in reliability or effectiveness are justified by corresponding gains in wearability.

The purpose of this section is to review the further development of the LSI undertaken by Wyle Laboratories, and to describe methods for applying the LSI in the PFD approval process.

A revision of the life-saving index was made necessary by data collected by Wyle which showed on the one hand that PFD wear is very low, but on the other hand that PFDs are quite effective when held or donned in the water. These considerations suggest that it may be cost effective to consider PFD accessibility as well as wear. An important point to consider is that accessibility is probably easier to change than wearability, i.e., it will be easier to induce boaters to keep PFDs accessible than to wear them, since the former involves less discomfort.

Using accessibility as a supplement to PFD wear requires a reconsideration of PFD physical effectiveness. In studying the effectiveness of PFDs, previous researchers have assumed that they would be worn. The present report considers PFD effectiveness when held or donned in the water as well as when worn. This revision also allows for the evaluation of throwable (e.g., Type IV) PFDs.

The following equation represents the life-saving capability of an individual PFD. It is presumed that the physical effectiveness of a PFD depends upon whether it is worn or held, hence two types of effectiveness appear in the equation. The equation also provides for the possibility that an accessible PFD may be donned after the victim of an accident enters the water.

[3] See section 5.3 of this report.

$$LSI = R\left[I_W E_W + P_D I_{AC} E_W + (1 - P_D) I_{AC} E_H\right]$$

where:

I_W	=	The probability that the PFD is worn immediately prior to entering the water in an accident
I_{AC}	=	The probability that the PFD is accessible to a boater but not worn immediately prior to entering the water in an accident
P_D	=	The probability that the accident victim dons the PFD in the water
E_W	=	The physical effectiveness of the PFD when worn
E_H	=	The physical effectiveness of the PFD when held
R	=	The index of reliability; i.e., the probability that the PFD performs as designed.

Note that PFD accessibility is defined in terms of the situation prior to an accident, since accessibility after an accident is extremely difficult to measure. Depending on their placement, some devices which are accessible during normal boating activity may not be accessible after an accident. The LSI may have to be further amended to accommodate this problem. This question will be addressed in Phase II of the present project.

The three terms in the above equation take into account three modes of PFD use. Each mode contributes to the overall life-saving capability of the PFD. The left-most term covers the possibility that the PFD is worn before as well as after the victim enters the water. The middle term allows for the possibility that the PFD is donned after the victim has entered the water. The third term covers the possibility that the victim holds or rests upon the PFD rather than donning it in the water. It was assumed that the PFD will be held or rested upon if it is accessible to the victim in the water and not donned. This assumption will also be checked in subsequent work.

In the application of the LSI to the PFD approval process, estimates of the various indices will be obtained through the methods outlined in Sections 4, 5, and 6 of this report. The LSI will then be computed for the PFD submitted for approval and compared to a minimum or

(119)

standard LSI as established by the Coast Guard. Only those PFDs which meet or exceed the minimum LSI would be approved. The minimum LSI could be established as the highest number which allows all, or some proportion, of currently approved PFDs to pass.

In addition to establishing a minimum LSI, the Coast Guard may deem it desirable to establish minimum standards for the indices of effectiveness and reliability. In order to accomplish the objective of stimulating manufacturers to develop better PFD designs, especially more wearable designs, these minimums may have to be slightly lower than the current levels of effectiveness and reliability for approved PFDs.

Recommendations for minimum values will be developed through the work on alternate PFD design concepts in Phase II of this project. A variety of hybrid and inflatable devices (and possibly also fixed buoyancy devices) will be procured. The safety benefits of these devices as reflected in the LSI will be evalulated in order to recommend minimums for the effectiveness and reliability indices.

4.0 PHYSICAL EFFECTIVENESS

4.1 INTRODUCTION

The goal of the physical effectiveness component of the PFD project is to develop a method for predicting or evaluating the effectiveness of existing and future PFD designs. The method should be sufficiently general and flexible so that it can be applied to PFD designs still in the conceptual stage, or at least to prototypes of advanced PFDs.

The physical effectiveness of a PFD is defined as the probability that the device keeps the wearer floating in a position which permits continuous breathing. In order to satisfy this criterion, the device must: (a) have sufficient buoyancy, and (b) maintain the individual in a vertical or slightly backward-leaning orientation. The principal measure of orientation is the equilibrium angle, defined as the angle between vertical and the center line of the wearer's body. (See ADL[1] report for definition of the center line.)

Previous research on physical effectiveness has been conducted by Arthur D. Little, Inc. [1] (ADL), Operations Research, Inc. [2] (ORI) and Underwriters' Laboratories [3] (UL). The previous work consists of an attempt to mathematically model the buoyancy of the human body and PFDs, and tests designed to validate the model. Unfortunately, the mathematical model has very little predictive power. The ORI report concludes:

> "....inherent inaccuracies in the measurements used in this work for the various vector quantities are too great to permit useful predictions of equilibrium angle using the flotation theory of Reference 1 [1]."

Aside from the inability of the mathematical model to generate useful predictions, other problem areas in the approach of previous work have become apparent. The previous research focused exclusively on the effectiveness of PFDs when worn. However, studies

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[1] Arthur D. Little, Inc., Buoyancy and Stability Characteristics of the Human Body in Fresh Water, 1972. NTIS No. AD-708-188.

[2] Dayton, R.B., Study of the Hydrostatic Moments of the Human Body and PFD, Operations Research, Inc., 1974.

[3] Underwriters Laboratories, Investigation of the Performance of Personal Flotation Devices, August, 1975. NTIS No. AD-A017-101.

conducted by Wyle Laboratories [4], ORI [5], and the National Safety Council [6] indicate that the rate of PFD wear is very low (e.g., the overall percentage of people wearing PFDs under normal conditions is approximately 7% according to the Wyle study). Since PFD wear is so low, it is very likely that an accident victim will not be wearing a PFD when he enters the water. Therefore, it is important to consider PFD effectiveness when held or donned by the victim after he enters the water.

It is also clear from previous research and accident investigations that victims often enter the water quickly and unexpectedly. Sudden impact with the water may cause a PFD to change position on the wearer's body and alter the PFD's effectiveness.

A third problem which should be addressed is the effect of body posture and configuration on effectiveness. For example, the position of the victim's head (whether held erect, forward, or back) and whether he adopts a relaxed, open position or closed, huddled position in the water will affect the ability of the PFD to provide the proper orientation and buoyancy.

4.2 APPROACH

Wyle's initial approach to the PFD effectiveness problem was to refine the human body buoyancy model formulated by Arthur D. Little, Inc.[1] In any modeling effort it is necessary to make certain assumptions in order to make the problem manageable. In the case of the human body buoyancy model a reexamination of some of the assumptions might lead to better predictive capability.

One specific area which Wyle addressed in this effort was the influence of physiological characteristics not accounted for in previous applications of the model. Most important of these was the relative separation and orientation of the center of gravity of the subject and his center of buoyancy.

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[4] See Section 5.3 of this report.

[5] Operations Research, Inc., A Study of Factors Influencing the Wearability of PFD's in Recreational and Work Environments, 1974. NTIS No. AD-A011-211.

[6] Bryk, J.A. and Schupack, S.A., Boating Safety: The Use of Personal Flotation Devices, National Safety Council, September, 1974.

All the many documented studies to date confirm that the living human body is a dynamic system, so that its center of gravity location with reference to the surroundings or even with reference to anatomical landmarks over a duration can be specified only with inherent uncertainty. If the body is undergoing acceleration or a change in attitude, the resultant shift of forces will further alter the center of gravity location.

Likewise, the center of buoyancy acts much like the center of gravity with the exception that it is the location of the center of gravity of the fluid displaced by the submerged portion of the body.

In water as in air, the body fluids are redistributed as the attitude changes. The lung volume changes as the individual breathes. The relative positions of the body segments change as the attitude in water changes. The living body even when unconscious, is a dynamic system and the center of gravity (CG) and center of buoyancy (CB) are constantly changing.

The Arthur D. Little, Inc. (ADL)[1] report on the buoyancy and stability characteristics of the human body in fresh water assumed a rigid body. However, mobility of the extremities can have a definite effect on the location of a body's center of gravity and center of buoyancy as shown in Section 4.3 of this report.

As Wyle began work on refining the human body buoyancy model, it soon became clear that a host of complicating factors would have to be taken into consideration before the model could generate useful predictions. At the same time it became obvious that the effectiveness problem is more general than that of supporting an unconscious wearer in the water. The low rate of wear of PFDs suggests the need for methods of evaluating the effectiveness of a PFD when held or donned in the water, as well as where worn. These considerations led to the formulation of a revised approach to PFD effectiveness. The new approach was presented in the second interim report on PFD research and approved by the Coast Guard Contract Monitor on 16 March, 1976.

The revised approach investigates two alternative avenues to development of a method for evaluating PFD effectiveness. One of these is a set of general design criteria for PFDs. The other is a test method which uses a human simulator or test dummy. A key characteristic of both of these methods is that they are entirely empirical. The development of the method and the process of evaluating PFDs for approval is based entirely upon laboratory test results. The methods involve no mathematical model and no assumptions about the buoyancy characteristics of the human body.

Further explanation of the methods is in order. The general design criteria will consist of a list of general PFD properties which are associated with effective performance. The necessary set of PFD properties which insure effective performance will be established by testing a carefully selected sample of human subjects. Subjects will be selected so as to represent proportions of the boating population in terms of height, weight, and body type. Norms for height, weight, and body dimensions are available in numerous sources. A wide variety of PFDs will then be tested on each of the selected subjects. As each PFD is tested, its properties on each of several critical dimensions will be recorded along with its performance on several measures. The performance measures and PFD properties to be recorded are shown in Figure 4-1. The performance of the PFD on each measure will be expressed in terms of an estimated percentage of the boating population for which the PFD exhibits acceptable performance. After a large sample of PFDs is tested, PFD properties will be correlated with selected minimum levels of performance. For example, the minimum amount of buoyancy required to support 90% of the boating population may be selected as a standard. In a similar fashion, locations of the center of buoyancy of the PFD relative to reference points on the wearer's body will be correlated with the ability of the PFD to maintain or turn a proportion of the boating population to vertical or face-up position in the water.

A criterion for the location of the center of buoyancy of PFDs can then be established in terms of acceptable ranges on each of three spatial coordinates. The end product of this approach would be a set of general design requirements. It is important that the requirements be general (e.g., specifying a range of acceptable locations for the center of buoyancy) rather than specific (e.g., specifying one particular type of PFD design). The advantage of the general criteria is that they allow the manufacturer to come up with innovative, hopefully more wearable, devices.

PFD Identification			PFD Properties								Performance Measures				
Manufacturer	Model No.	Type	Amount of Buoyancy	Location[a] of Center of Buoyancy			Type of Actuator	Placement of Actuator			b	c	d	e	f
				x	y	z		x	y	z					

a Coordinates are specified relative to reference points on the wearer's body.

b Estimated proportion of population this PFD would maintain in a vertical or slightly backward position (assume relaxed or unconscious wearer).

c Estimated proportion of population this PFD would turn from a face in the water to a vertical or slightly backward position (assume relaxed or unconscious wearer).

d Estimated proportion of the population for which this PFD provides at least a minimum effective buoyancy (the minimum will be defined in terms of the height of the wearer's lower respiratory passage above water).

e *Time required to achieve minimum acceptable buoyancy after submergence.*

f Percentage of PFD above lower respiratory passage after human S or dummy of appropriate size jump into water.

FIGURE 4-1. DATA SHEET TO BE USED IN THE DEVELOPMENT OF GENERAL DESIGN CRITERIA FOR PFD EFFECTIVENESS

A test method for evaluating the effectiveness of PFDs would use an anthropomorphic dummy. With the help of the Coast Guard, Wyle has recently obtained an immersible dummy from the FAA Aeronautical Center in Oklahoma City. This dummy will be used to study the feasibility of developing the test method approach. The process of developing a test method utilizing a dummy is schematized in Figure 4-2. The first step is to determine what type of human body the dummy must simulate. For instance, what are the characteristics of the boater who represents the 95th percentile in terms of buoyancy requirements? Clearly, the main consideration here is body density. What are the characteristics of the boater who represents the 95th percentile in terms of turning or maintaining a wearer in a vertical or head-back position? This problem is more complex since it depends on the distribution of mass of the body.

Several answers may have to be formulated depending on the orientation of the person as he enters the water, and perhaps the type of PFD. The [redacted]t the top ~~of~~ Figure 4-2 represents this first step. The output of this step will be a description of the critical cases which a dummy must simulate.

The second step is to determine whether the dummy can simulate the critical cases. A dummy, no matter how sophisticated, cannot reproduce all of the dynamic properties of the human body. The redistribution of bodily fluids with changes in orientation and limb movements are two such properties. Tests will be conducted to determine whether the dummy can reliably reproduce the performance of a human subject of similar dimensions in the water wearing a PFD. If the dummy reproduces the results obtained with a human subject with a high level of confidence, then guidelines for a test method will be developed. Once a test method is established, validation studies will be undertaken. A new sample of PFDs of widely varying designs will be tested both with the dummy and selected human test subjects. The results will be compared to determine whether the dummy test reliably predicts the performance of the PFDs with an acceptable proportion of the human subjects. The validation studies will also define test requirements which a PFD must satisfy to reach various levels of effectiveness. The level of effectiveness (or effectiveness index) for a PFD will be expressed in terms of proportions of the boating population for which the PFD will function adequately.

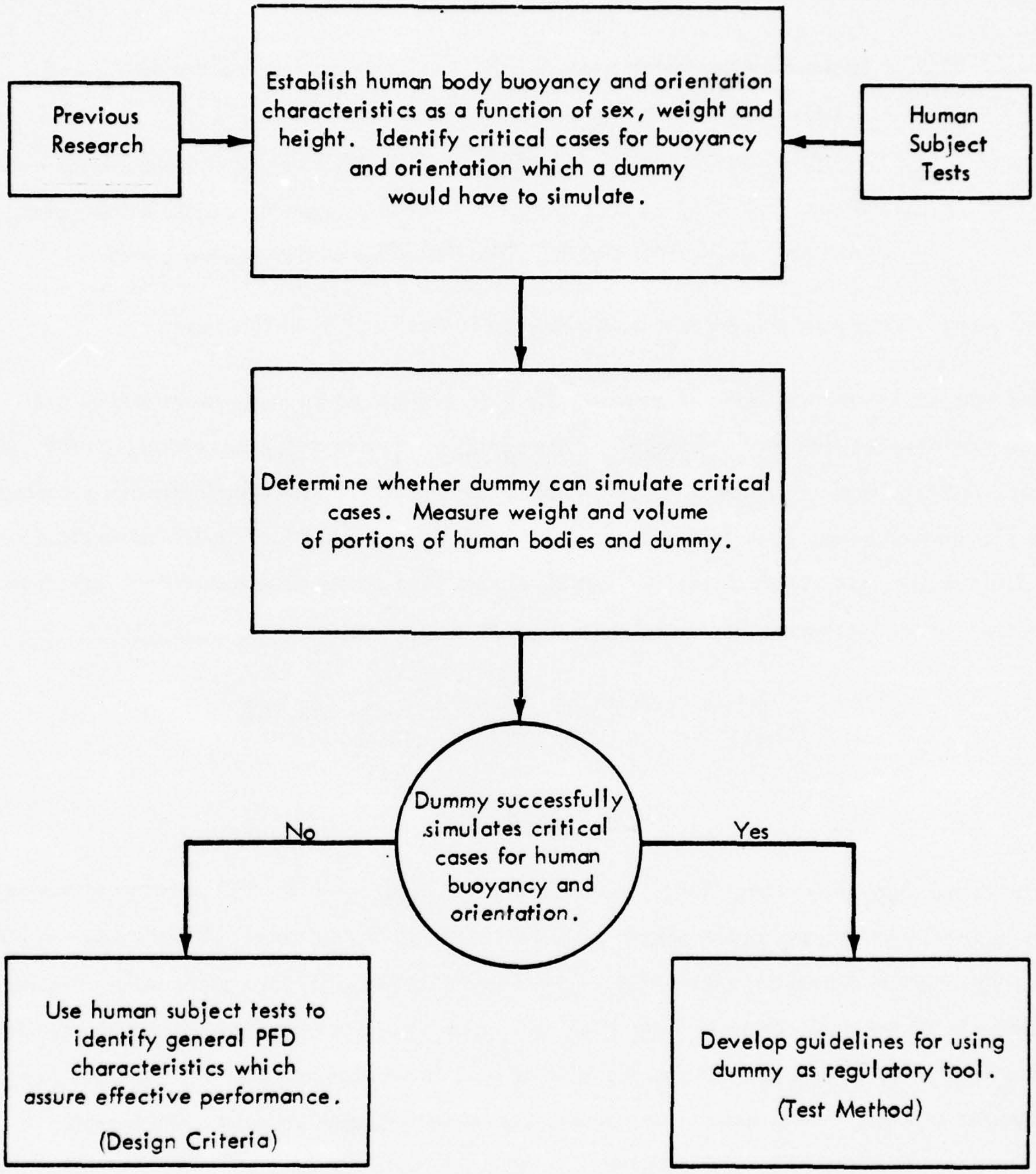


FIGURE 4-2. DEVELOPMENT OF A TEST METHOD USING A DUMMY

During Phase I of the present project a pilot experiment on PFD effectiveness with human subjects was conducted. This experiment had two main objectives:

1) To develop the test procedure and apparatus necessary to the development of both the design criteria and the test method.

2) To collect preliminary information on PFD effectiveness in a variety of modes of use, including donning a PFD in the water, holding a PFD in the water, swimming with a PFD and falls into the water while wearing a PFD.

The effectiveness pilot experiment is documented in Section 4-4 of this report.

The next section of this report summarizes the study conducted by Wyle to determine the effect of limb position on the location of the center of gravity of the human body. This work was conducted early in Phase I in an attempt to salvage the mathematical modelling approach to PFD effectiveness. It soon became apparant that the mathematical modelling approach would require many years to produce useful results. The approach was therefore abandoned in favor of the more cost-effective empirical approach.

4.3 SOME EFFECTS OF LIMB POSITION ON THE CENTER OF GRAVITY OF THE HUMAN BODY

4.3.1 Introduction

The Human Buoyancy Model (HBM) is the theoretical tool by which PFD physical effectiveness is to be predicted in terms of the wearer's position stability in the water. It describes the forces acting upon the system composed of the body and a PFD while in the water. Also, the model accounts for the application of a righting moment necessary to rotate an unconscious wearer to a face upright attitude. The model must be able to yield repeatable and predictive results from the stability characteristics of a single wearer with enough accuracy that the physical effectiveness of the PFD for a group can be estimated with confidence. To date models proposed have not produced results which could be either predictive or repeatable over a range of human subject types. Additional effort must be expended to establish the validity and accuracy of an HBM before it can be considered a useful tool. Physiological characteristics

not accounted for in previous models will be considered, particularly the changing positions of the center of gravity and the center of buoyancy, and the weight of the PFD.

The forces on the system will be as shown in Figure 4-3 and will be directed along the y-axis. At equilibrium these forces are:

$$0 = B_b + B_\ell + B_p - W_b - W_p$$

where $B_b = \rho_w V_s$ and

$$B_\ell = \rho_w \Delta V_\ell$$

and

B_b is the buoyancy provided by the body which acts at the center of buoyancy

B_ℓ is the buoyancy provided by the lungs referenced to the bottom of the breathing cycle which acts at the center of lung volume

B_p is the buoyancy provided by the PFD which acts at the center of gravity of the PFD

W_b is the weight of the subject which acts at the center of gravity of the body

W_p is the weight of the PFD which acts at the center of gravity of the PFD

ρ_w is the density of water

ΔV_ℓ is the change in lung volume referenced to the bottom of the breathing cycle (functional residual capacity)

V_o is the total volume of the subject's body at the bottom of the breathing cycle

V_s is the volume of the submersed portion of subject's body at the bottom of the breathing cycle

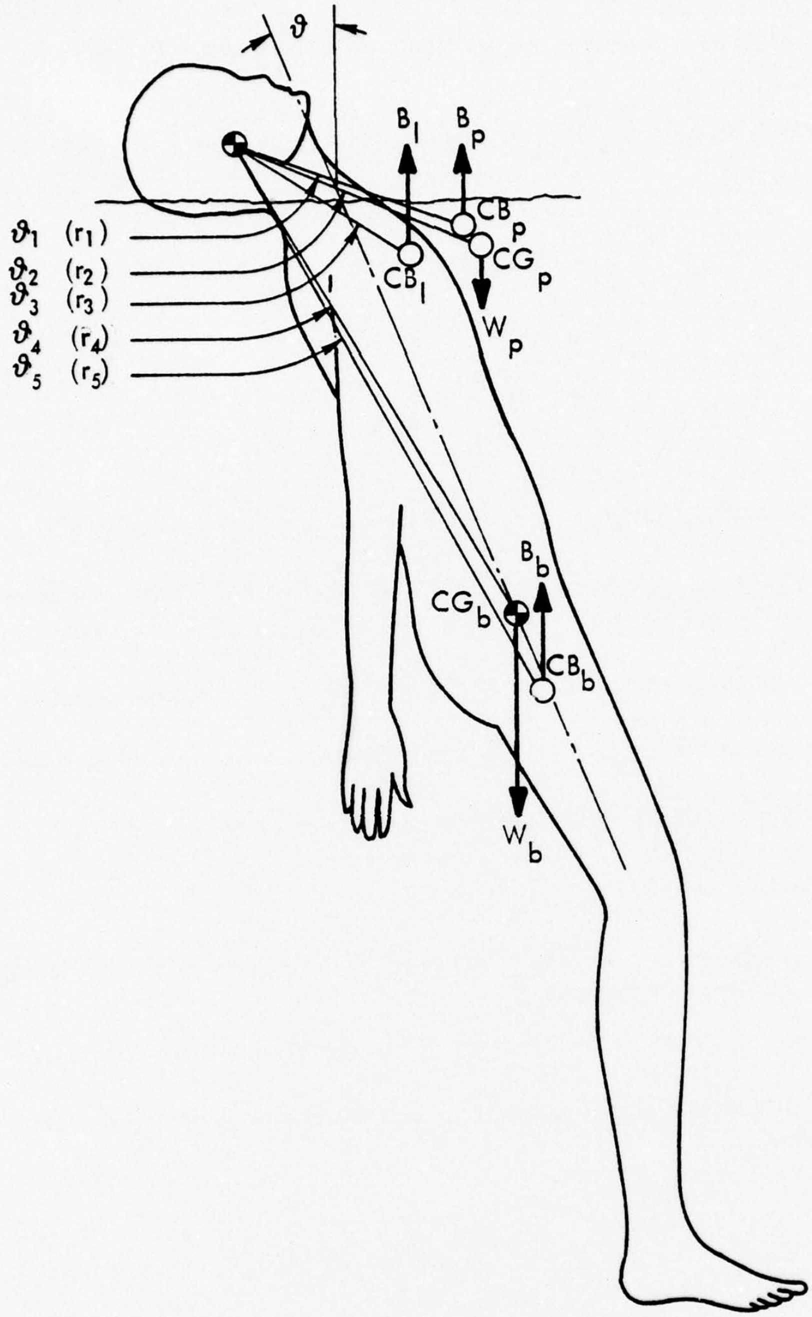


FIGURE 4-3. BODY/PFD FORCES AND MOMENTS

Each of the above forces will tend to rotate the system about its center of mass. When the point of rotation is chosen to be the center of floated volume, the magnitude of the total moment is:

$$M(\theta) = B_p r_1 \sin(\theta + \theta_1) - W_p r_2 \sin(\theta + \theta_2) + \rho_w \, \Delta V \, r_3 \sin(\theta + \theta_3)$$
$$- W_b r_4 \sin(\theta + \theta_4) + \rho_w V_s r_5 \sin(\theta + \theta_5)$$

where θ is the equilibrium angle, the inclination of the body centerline to the vertical.

The system composed of the subject and the PFD is considered a dynamic system. The lung volume change, the relative position of the body components, and the distribution of the body fluids contribute to the migration of the center of gravity. Similarly, the location of the center of buoyancy changes as it is the location of the center of gravity of the fluid displaced by the submersed part of the body. As the body weight component W_b and the submerged volume V_s is so large relatively in magnitude, it must be assumed that they are supercritical in their importance in the model. The body weight is a measurable quantity and the submerged volume can be estimated from the weight of the submerged body components. The radial arm lengths r_4 and r_5 must be estimated from limb attitudes.

The location of these two centers of gravity can be approximated by considering the center of gravity as a composite CG of the body components. Allow the x-axis to be the lateral axis, the y-axis to be the vertical axis, and the z-axis to be the "depth" axis as shown in Figure 4-4. The body can be considered as being composed of N elements of known weight W_n and known center of mass coordinates x_n, y_n, z_n. Then the total weight and total submerged weight of the body can be expressed as

$$W_b = \sum_{n=1}^{N} W_n \quad \text{and} \quad W_s = \sum_{n=1}^{N_s} W_{n_s}$$

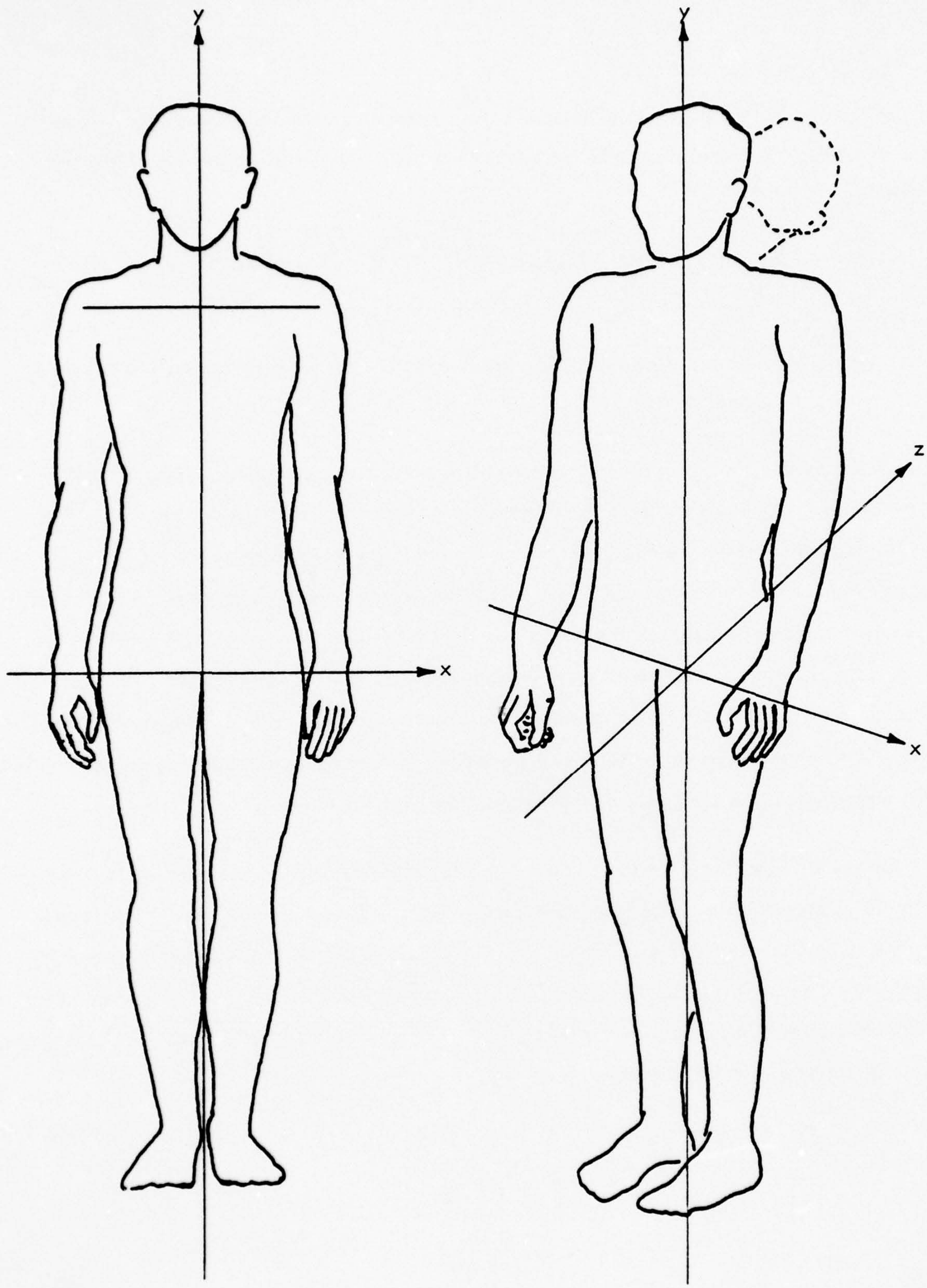


FIGURE 4-4. BODY COORDINATE SYSTEM WITH REFERENCE AT ISCHIA

The coordinates of the center of gravity for the system composed of the individual components is then

$$\bar{x} = \frac{\sum^{N} X_n W_n}{\sum W_n} \qquad \bar{y} = \frac{\sum^{N} Y_n W_n}{\sum W_n} \qquad \bar{z} = \frac{\sum^{N} Z_n W_n}{\sum W_n}$$

If X_h, Y_h, Z_h are the coordinates of the center of mass of the head and neck component, X, Y, Z are the coordinates of the CG and $\bar{X}_s$, $\bar{Y}_s$, $\bar{Z}_s$ are the coordinates of the CB, then the radial distances are

$$r_5 = \left((\bar{X} - X_h)^2 + (\bar{Y} - Y_h)^2 + (\bar{Z} - Z_h)^2\right)^{1/2} \quad \text{and}$$

$$r_4 = \left((X - X_h)^2 + (Y - Y_h)^2 + (Z - Z_h)^2\right)^{1/2}$$

The substitution of these terms into the model equation is an uncomplicated but laborious calculation, which suits it for computer application. Also, the repetitive calculation required for a sensitivity analysis, an analysis which weights or classifies a parameter according to its effect in the model, is performed more easily by computer methods.

4.3.2 Computer Program Aid

The computer application must perform several functions to be an effective tool in the human buoyancy modeling. It must be designed to:

- Accommodate several types of data inputs
- Offer a choice of several types of information lists
- Perform the calculations necessary to determine the coordinates of center of gravity and center of buoyancy
- Calculate the parameters in the Human Buoyancy Model
- Determine the effect on the Model of varying one or more parameters.
- Offer flexibility to facilitate rewrites dictated by test data.

Figure 4-5 represents a preliminary design for a computer program. It should be written in this mode to allow any combination of functions to be performed in any order. It has initially four main functions, and each function has several subfunctions described as follows:

READ allows inputs on cards such as the subject body measurement data, the spatial coordinates or angle inclination of the extremities, the parameters which offer a physical description of the PFD, the test parameter data, and the test results.

CALCULATE determines limb coordinates from extremity angle inclinations and the reverse, determines center of mass and center of gravity coordinates, and determines inputs for the Human Buoyancy Model.

HUMAN BUOYANCY MODEL
calculates qualities for Human Buoyancy Model parameters.

LIST outputs a table describing the center of mass and center of buoyancy coordinate calculations, a table describing the human buoyancy information, and a table which relates the variation of one or more parameters to a single parameter.

To illustrate an example, suppose the effects of leg motion upon the coordinates of the centers of mass and buoyancy were desired. These functions would supply that information:

1. READ Subject Body Measurement Data
   Input the body measurements of the subject.
2. CALC Calculate Body CG/CB Coordinates
   The center of mass is calculated for the standing subject with reference at the ischia.
3. LIST CB/CG Information
   The center of mass information list is output. This contains the center of mass coordinates for each component, its moment to the reference, and the composite center of mass.

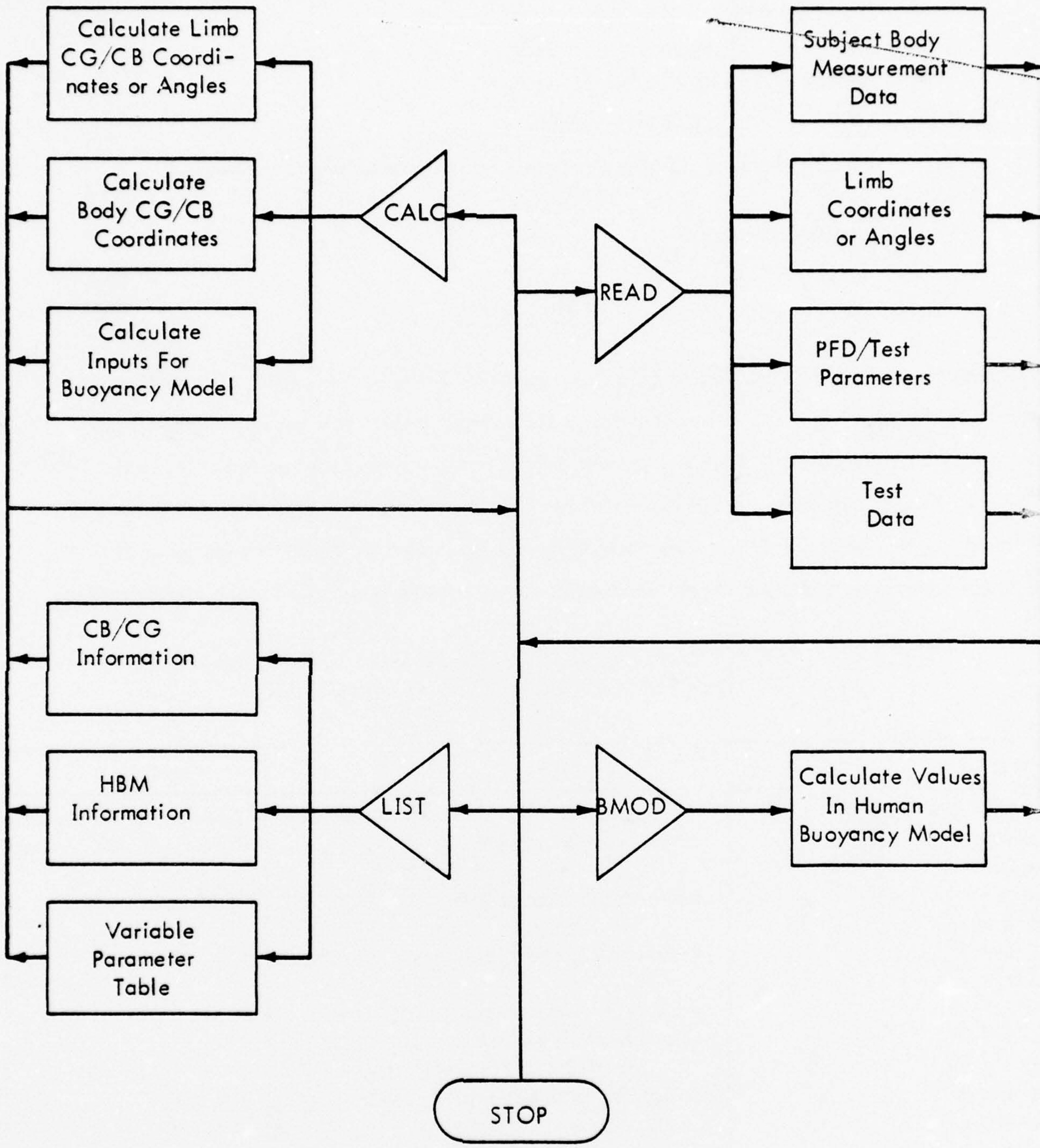


FIGURE 4-5. PRELIMINARY DESIGN OF COMPUTER PROGRAM AID

4. READ Limb Coordinate or Angle
Input the angle of the upper leg to the y-axis.

5. CALC Calculate Body CG/CB Coordinates
Determine the new center of mass.

6. LIST CB/CG Information

7. Perform 4.thru 6. for each angle or angle combination desired.

8. STOP.
End program usage.

4.3.3 Results

The program has been developed to calculate the coordinates of the center of mass and the center of buoyancy of a subject according to his limb attitude. The body components are identified by a number and each component has a corresponding angle as shown in Table 4-1. These particular angle constraints represent the case of motion restricted to the y-2 direction. Physically, this describes limb motion which has no transverse (x-direction) motion. If limb attitudes remain symmetrical about the y-axis, the unconscious subject is then approximated.

TABLE 4-1. BODY COMPONENT NUMBERS AND ASSOCIATED ANGLES WITH MOTION RESTRICTED TO y-z DIRECTION

COMPONENT	NUMBER	ANGLE	LIMITS
Head and Neck	1	Inclination of head to body centerline	30 to front, 60° to back
Upper arm (l)	2	Upper arm to vertical	90 to front, 30° to back
Upper arm (r)	3		
Lower arm (l)	4	Lower arm to upper arm	equals zero
Lower arm (r)	5		
Hand (l)	6	Considered to be extension of lower arm	
Hand (r)	7		
Trunk	8	Flexure of trunk to body centerline	equals zero
Upper leg (l)	9	Upper leg to vertical	
Upper leg (r)	10		
Lower leg (l)	11	Lower leg to upper leg	vertical
Lower leg (r)	12		
Foot (l)	13	Considered to be extension of lower leg	
Foot (r)	14		

From the literature body measurements for the 50 percentile man such as height, weight, and transverse and vertical measurements and distances between joints were obtained. Estimates of the percentage weight of the body components were also obtained and used in the calculation of component weight. The coordinates of the component center of mass were calculated from joint-to-joint measurements and published estimates of percentage of limb length at which to locate the center of mass. The results of the CG calculation are shown in Figure 4-6; the computed value is 5.57; the published value is 5.40.

Figures 4-7 and 4-8 illustrate the effect upon center of mass coordinates by extending an arm forward 15° and 30°, respectively.

4.4 EFFECTIVENESS PILOT EXPERIMENT

This section describes the methods and results of the pilot experiment on PFD effectiveness. This experiment provided an opportunity to develop the test methods to be used in a later full-scale experimental effort. The results suggest a number of interesting conclusions with respect to PFD effectiveness. The full-scale experiment to be conducted in Phase II of this project will employ substantially the same apparatus and test procedure employed in the pilot investigation, but would use a wider variety of PFDs and a larger number of subjects (Ss).

4.4.1 Method

In the pilot study, each of six Ss underwent a standardized test procedure once with each of three types of PFDs. In all, 18 repetitions of the test procedure were run. The procedure included the following phases:

Phase	Activity
1	Screen Ss on health-related measures, complete consent form, record general test information, obtain body measurements.
2	Administer wearability test.
3	Weigh the S dry and in the water .

STANDING BODY

COMPONENT	WGT LBS	ANGLE DEGREES	COORDINATES, IN X	Y	Z	MOMENTS, IN-LBS WX	WY	WZ
1	16.51	0.00	0.00	31.95	0.00	0.00	527.56	0.00
2	5.68	0.00	8.38	16.84	0.00	47.58	95.58	0.00
3	5.68	0.00	-8.38	16.84	0.00	-47.58	95.58	0.00
4	3.27	0.00	8.00	6.43	0.00	26.14	21.01	0.00
5	3.27	0.00	-8.00	6.43	0.00	-26.14	21.01	0.00
6	1.12	0.00	7.90	-1.30	0.00	8.83	-1.45	0.00
7	1.12	0.00	-7.90	-1.30	0.00	-8.83	-1.45	0.00
8	78.78	0.00	0.00	10.95	0.00	0.00	862.60	0.00
9	18.06	0.00	1.10	-5.54	0.00	19.94	100.10	0.00
10	18.06	0.00	-1.10	-5.54	0.00	-19.94	100.10	0.00
11	7.74	0.00	4.00	19.81	0.00	30.96	153.36	0.00
12	7.74	0.00	-4.00	19.81	0.00	-30.96	153.36	0.00
13	2.49	0.00	2.36	31.31	2.36	5.89	-78.09	5.89
14	2.49	0.00	-2.36	31.31	2.36	-5.89	-78.09	5.89
	------					------	------	------
TOTAL	172.00					0.00	957.31	11.78

	X	Y	Z
CENTER OF MASS	0.00	5.57	0.07

FIGURE 4-6. COMPUTER LIST OF CENTER OF GRAVITY INFORMATION

STANDING BODY

COMPONENT	WGT LBS	ANGLE DEGREES	COORDINATES, IN X	Y	Z	MOMENTS, IN-LBS WX	WY	WZ
1	16.51	0.0	0.00	31.95	0.00	0.00	527.56	0.00
2	5.68	15.0	8.38	17.00	1.25	47.58	96.51	7.11
3	5.68	0.0	-8.38	16.84	0.00	-47.58	95.52	0.00
4	3.27	0.0	8.00	6.95	3.99	26.14	22.72	13.03
5	3.27	0.0	-8.00	6.43	0.00	-26.14	21.01	0.00
6	1.12	0.0	7.90	-0.51	5.97	8.83	-0.52	6.67
7	1.12	0.0	-7.90	-1.30	0.00	-8.83	-1.45	0.00
8	78.78	0.0	0.00	10.95	0.00	0.00	862.60	0.00
9	18.06	0.0	1.10	-5.54	0.00	19.94	100.10	0.00
10	18.06	0.0	-1.10	-5.54	0.00	-19.94	100.10	0.00
11	7.74	0.0	4.00	19.81	0.00	30.96	153.36	0.00
12	7.74	0.0	-4.00	19.81	0.00	-30.96	153.36	0.00
13	2.49	0.0	2.36	31.31	2.36	5.89	-78.09	5.89
14	2.49	0.0	-2.36	31.31	2.36	-5.89	-78.09	5.89
	------					------	------	------
TOTAL	172.00					0.00	960.84	38.59

	X	Y	Z
CENTER OF MASS	0.00	5.59	0.22

FIGURE 4-7. CENTER OF MASS FOR STANDING BODY WITH UPPER ARM AT 15° FROM VERTICAL

STANDING BODY

COMPONENT	WGT LBS	ANGLE DEGREES	COORDINATES, IN X	Y	Z	MOMENTS, IN-LBS WX	WY	WZ
1	16.51	0.0	0.00	31.95	0.00	0.00	527.56	0.00
2	5.68	30.0	8.38	17.49	2.42	47.58	99.26	13.73
3	5.68	0.0	-8.38	16.84	0.00	-47.58	95.56	0.00
4	3.27	0.0	8.00	8.49	7.70	26.14	27.75	25.16
5	3.27	0.0	-8.00	6.43	0.00	-26.14	21.01	0.00
6	1.12	0.0	7.90	1.79	11.53	8.83	2.00	12.88
7	1.12	0.0	-7.90	-1.30	0.00	-8.83	-1.45	0.00
8	78.78	0.0	0.00	10.95	0.00	0.00	862.60	0.00
9	18.06	0.0	1.10	-5.54	0.00	19.94	100.10	0.00
10	18.06	0.0	-1.10	-5.54	0.00	-19.94	100.10	0.00
11	7.74	0.0	4.00	19.81	0.00	30.96	153.36	0.00
12	7.74	0.0	-4.00	19.81	0.00	-30.96	153.34	0.00
13	2.49	0.0	2.36	31.31	2.36	5.89	-78.09	5.89
14	2.49	0.0	-2.36	31.31	2.36	-5.89	-78.09	5.89
	------					------	------	------
TOTAL	172.00					0.00	971.19	63.57

	X	Y	Z
CENTER OF MASS	0.00	5.65	0.37

N*EXIT*

FIGURE 4-8. CENTER OF MASS FOR STANDING BODY WITH UPPER ARM AT 30° FROM VERTICAL

(142)

4	Allow S to acclimate in water .
5	S ranks the ease of holding the PFD in several positions.
6	S attempts to don the PFD in the water; collect ratings and time.
7	S swims the length of the tank with and without the PFD; collect ratings.
8	S's buoyancy and equilibrium angle are observed with body in each of three starting positions.
9	S falls into the water wearing the PFD; observe S's buoyancy and equilibrium angle and any change of position of PFD on wearer.
10	S compares several PFDs for ease of holding in most preferred position (this phase is run only on the last test day for each S).

The three types of PFDs employed were an AK-1 standard yoke (Type II), an adjustable buoyant vest with zipper (Type III), and a buoyant cushion (Type IV). The order in which each S used the three PFD's was counterbalanced to control for practice effects. The test procedure for each S with a particular PFD required approximately 45 minutes. Moving and still pictures were taken at pre-selected points in the procedure.

Subject Selection

The Ss were selected on the basis of weight. Three members of each sex were employed. One S of each sex was chosen so as to approximate the 10th percentile of weight for his or her sex, another pair was chosen to approximate the 50th percentile, and another to approximate the 90th percentile. Weights and other characteristics of the test Ss are shown in Table 4-2.

Apparatus

The overall dimensions of the tank are 37 ft by 10 ft. The deep end, which is comprised of the last 10 ft, is 11.5 ft deep. The remainder of the tank (27 ft) is 5.5 ft at the center. The actual water line was about 6 in. below the rim of the tank. The tank is located in the Marine Technology Building at Wyle Laboratories in Huntsville, Alabama.

TABLE 4-2. CHARACTERISTICS OF THE SUBJECT

MEASUREMENT	SUBJECT					
	Female			Male		
	1	2	3	4	5	6
Weight (lbs) *						
Total (Dry)	118	125-1/4	157-1/2	129-1/4	165-3/4	216
Submerged to Suprasternal Notch	15-1/2	13-1/4	15-1/4	16-1/2	22-1/2	24-1/2
Submerged to Chin	11-1/2	8	10-1/2	11-1/2	16-1/2	18
Height (inches) **						
Total	63-1/2	65-1/4	68	64-1/2	70-1/2	68-1/2
Leg Inseam	30	32	33-3/4	28-3/4	33	31
To Suprasternal Notch	51-3/4	54-1/2	56-1/2	53-3/4	59-1/4	57-1/2
Chin to Suprasternal Notch	3-3/4	4	4-1/2	4	4	4
Circumference (inches) **						
Head	22	22-1/4	22-1/2	22-1/4	23	23-3/4
Neck	12-1/4	12-1/2	13	15	15	17
Shoulders	36-1/2	38-1/4	39-1/4	39-1/2	45	52
Bust/Chest	33	35-1/4	38	36	38-1/2	44-1/2
Waist	26	27-1/4	31-1/2	32	30-1/4	41-1/2
Hips	38	38	39-3/4	35	38-1/2	44
Upper Thigh	22	21-3/4	24-3/4	18-1/2	22	24
Calf	13-1/4	13-1/4	16	12-1/4	15	16-1/2

* All weights are accurate to within $\pm$ 1/4 lb.

** All measurements are accurate to within 1/4 inch.

Although the building where the tank is located in heated, the temperature of the water was low enough to require a recirculating water heater for the comfort of the swimmers. The chlorine content of the water was controlled to 1-3 ppm and the PH was adjusted to 7.4-7.6.

Two Type II (yoke), two Type III (vest), and two Type IV (cushion) were utilized for these tests. All had been subjected to a buoyancy test performed by Wyle Laboratories in addition to being CG approved and had passed the minimum criteria established for each type.

Three still cameras (all 35 mm) and one movie camera (16 mm) were utilized to photograph and record the various phases performed. The movie camera was positioned approximately 24 ft from the deep end along one side of the tank. It was used primarily for the donning and jumping-in phases of the test. Two 35 mm cameras were mounted on a fixed platform at the deep end of the tank and on the same side as the movie camera. The top mounted camera with a 50 mm lens was four inches above the rim of the tank and, consequently, 10 in. above the water line. The other fixed camera with a 35 mm lens (semi-wide angle) was mounted in an underwater plexi-glass housing 10 in. below the water line. It was angled downward at about an 8° angle. These two cameras had the capability of being triggered simultaneously and, thus, were able to photograph the total subject (above and below the water) at any particular instant. A white grid board, 3 ft x 4 ft was constructed and marked in 2 in. grids. This was installed at the deep end opposite the two fixed 35 mm cameras such that about half of it (18 in.) was out of the water and about half below the water line. Connected to it below the water was an extended grid fixture constructed of 1" x 1" wood strips (painted black) and sized to cover almost one entire side of the deep end to a depth of about 7.5 ft. The two fixed cameras were used primarily during Phase 8 to record the S's equilibrium angle and effective buoyancy. The third 35 mm camera was used as a hand-held roving-utility camera and to record other events as required.

A steel frame with a mounted chair seat was fabricated to facilitate the weighing of the subjects while in the water (see Figures 4-9 and 4-10). A load cell was hung from an overhead crane and the chair-frame was attached to the load cell. Output from the load cell was read

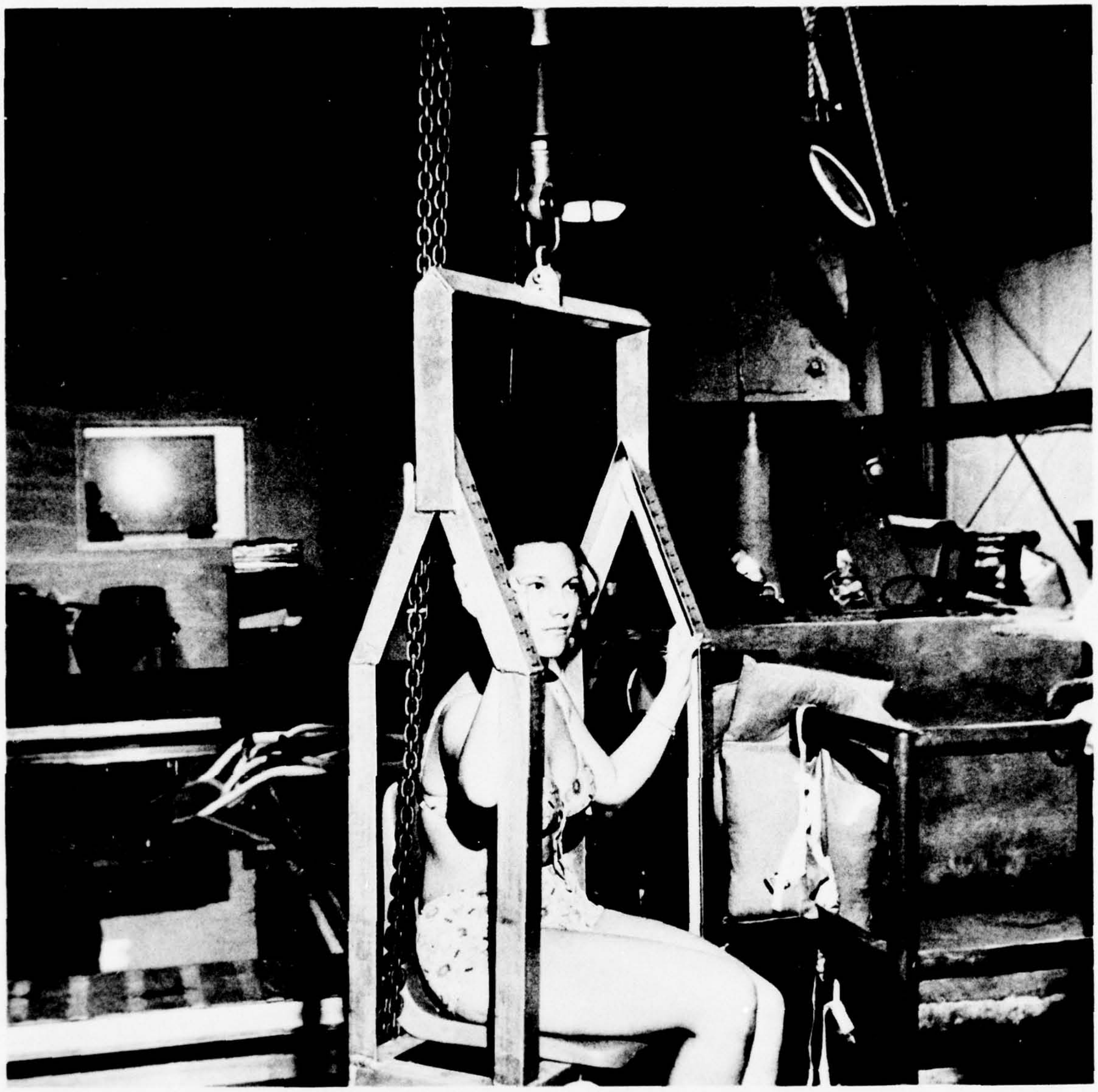


FIGURE 4-9. WEIGHING OF THE SUBJECT OUT OF WATER

FIGURE 4-10. WEIGHING OF SUBJECT IN WATER

from a digital voltmeter (DVM). Although the load cell and the DVM were in calibration, a test run with known weights was completed to verify the accuracy and linearity within the range utilized. The overall accuracy of the system was determined to be within $\pm$ 1/4 lb.

Index marks were located on the vertical support frame of the chair. The chair assembly was lowered into the water to the depth of the index marks and this weight was recorded. The weight in the water of the chair was calibrated by the index marks. When the subjects were lowered into the water to various depths, the in-water weight of the chair assembly was subtracted from the total indicated weight.

Procedure

The data sheet shown in Appendix 4-A shows the types of information collected during each phase of the procedure. The data sheet also summarizes the instructions given to S during the test procedure.

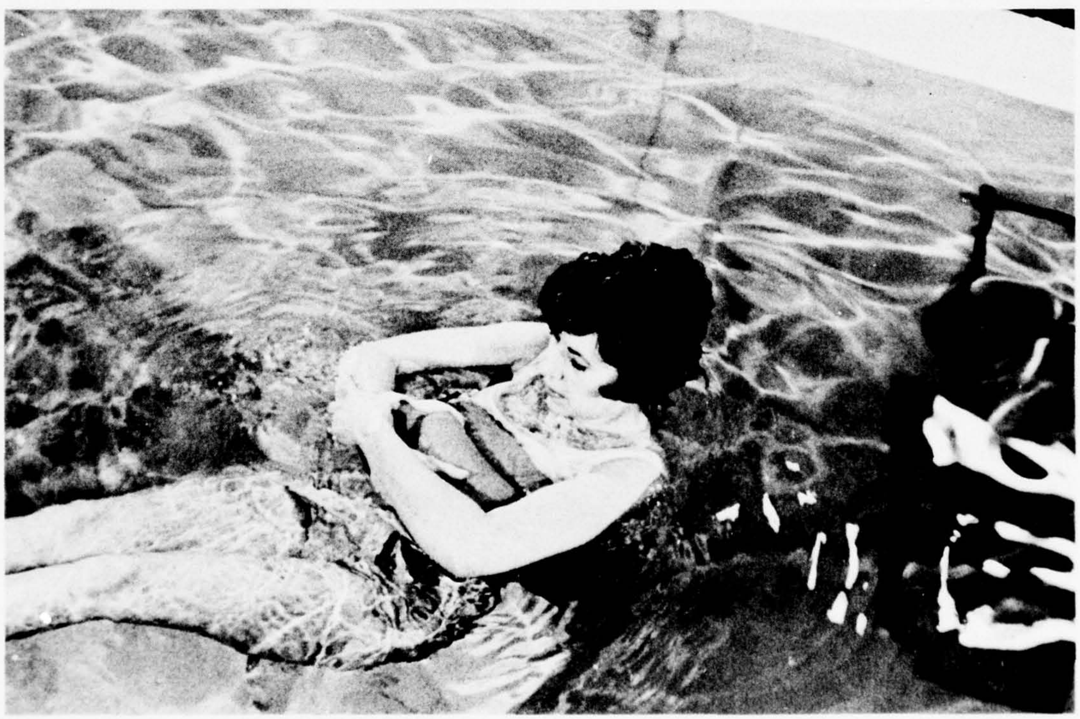
The health-related questions shown in Phase I were asked only in the S's first run through the test procedure. In addition to the information shown on the data sheet, S's blood pressure was taken prior to each run. All S's blood pressures fell within the normal limits. The body measurements were taken only on the first and second runs.

The wearability test (Phase II) was omitted for Type IV PFD's.

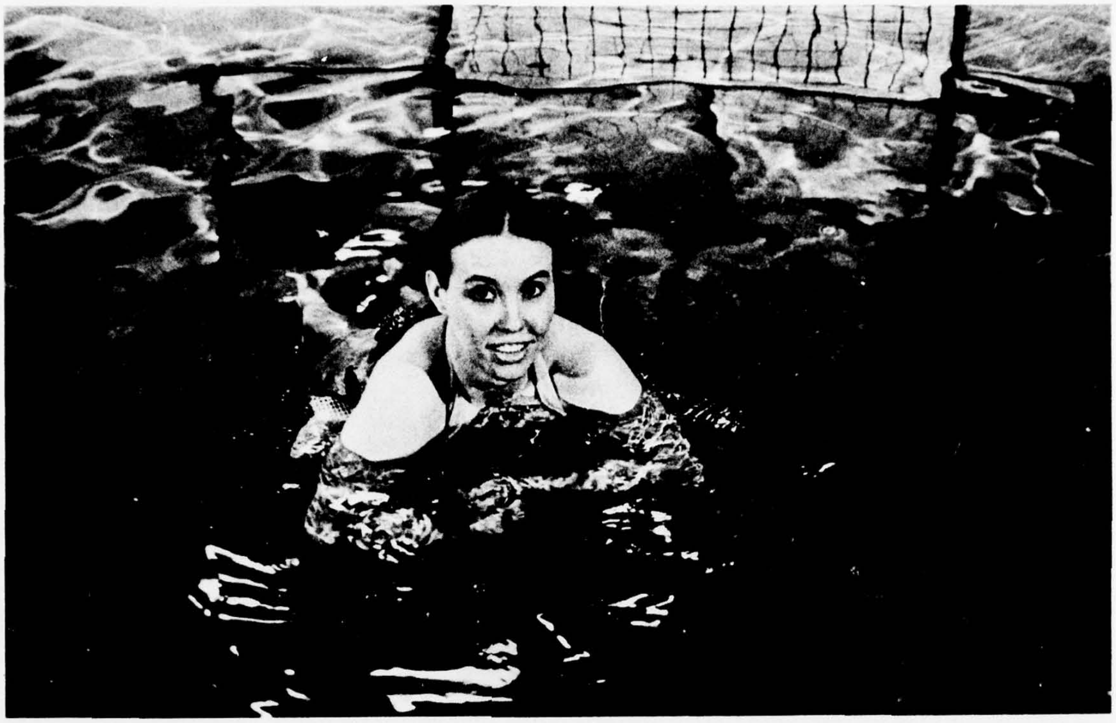
Phase III, weighing of the S, was repeated on each test run. The S was first weighed dry, wearing only a bathing suit. The S was then submerged to the suprasternal notch and weighed, and finally to the chin and weighed. In addition to the instructions shown on the data sheet, S was instructed to keep his or her head level during the weighing procedure.

In Phase V, S was first allowed several minutes to experiment with the PFD to find comfortable holding positions. The S was then asked to reproduce the position which required least effort, the second-least effort, etc. The S was given ample time to repeat positions and to change the rankings if he or she desired. The Experimenter (E) suggested positions which Ss did not discover for themselves. However, E was careful not to suggest to S that any position was better or worse than others. Still photographs were taken of each position (see Figure 4-11).

FIGURES 4-11A (ABOVE) AND 4-11B (BELOW). PFD HOLDING POSITIONS



FIGURES 4-11C (ABOVE) AND 4-11D (BELOW). PFD HOLDING POSITIONS



FIGURES 4-11E (ABOVE) AND 4-11F (BELOW). PFD HOLDING POSITIONS

FIGURES 4-11G (ABOVE) AND 4-11H (BELOW). PFD HOLDING POSITIONS

FIGURES 4-11I (ABOVE) AND 4-11J (BELOW). PFD HOLDING POSITIONS

FIGURES 4-11K (ABOVE) AND 4-11L (BELOW). PFD HOLDING POSITIONS

FIGURE 4-11M. PFD HOLDING POSITIONS

In Phase VI each S donned the PFD in water twice, and was timed and rated on both occasions. Moving pictures and a few stills were taken of the donning attempts (see Figure 4-12).

In Phase VII, S first swam the length of the tank without the PFD, then again wearing the PFD, and finally rated the PFD. One S declined to swim without the PFD.

In Phase VIII, S began in each of three starting positions head forward, head back, or huddled with arms wrapped around the knees. The S then relaxed and allowed the PFD to turn him or her to whatever position it took them. Tests in each of the three starting positions were repeated twice. The S was positioned in front of the grid, opposite the cameras. The S was positioned such that his or her frontal surface was in a plane perpendicular to the grid surface. The S was kept as close as possible to the grid without touching it. Photographs were made after S had settled into a stable position from fixed cameras just above and below the water line (see Figure 4-13).

On the first test day in Phase IX, S was instructed to step forward into the water from the top rung of a pool-side ladder at water level. On the second and third test days, S was also asked to fall backwards into the water from the same starting position. Falls from each position were executed at least twice on each test run. Falls with the Type IV PFD were executed three times — with the PFD held and worn in falls forward and held only in falls backward. Moving pictures were taken during the falls and still photos were taken of the S's final equilibrium position in the water.

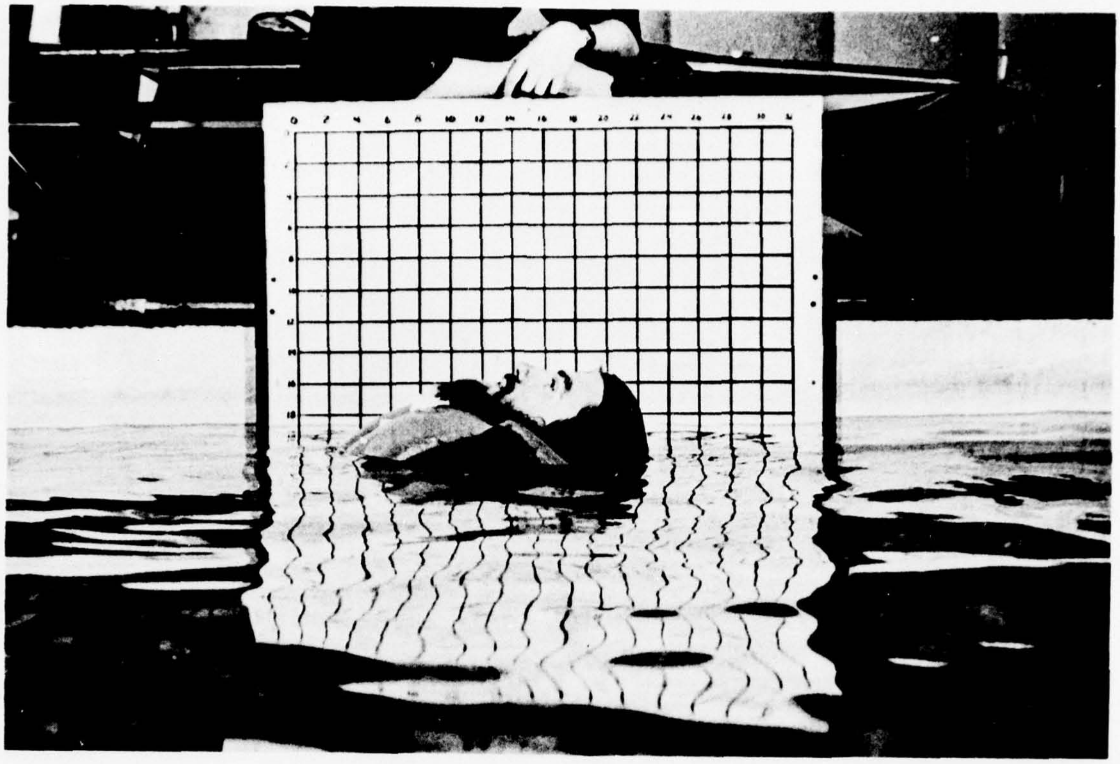
In Phase X, S was given all three types of PFD's. He was instructed to find the best holding position for each PFD (i.e., the position requiring least effort), and then to rank the PFD for ease of holding in their best positions. The S was encouraged to try a wide variety of positions for each PFD. In a few cases the best holding position selected by a S in Phase X did not agree with his selection in Phase V.

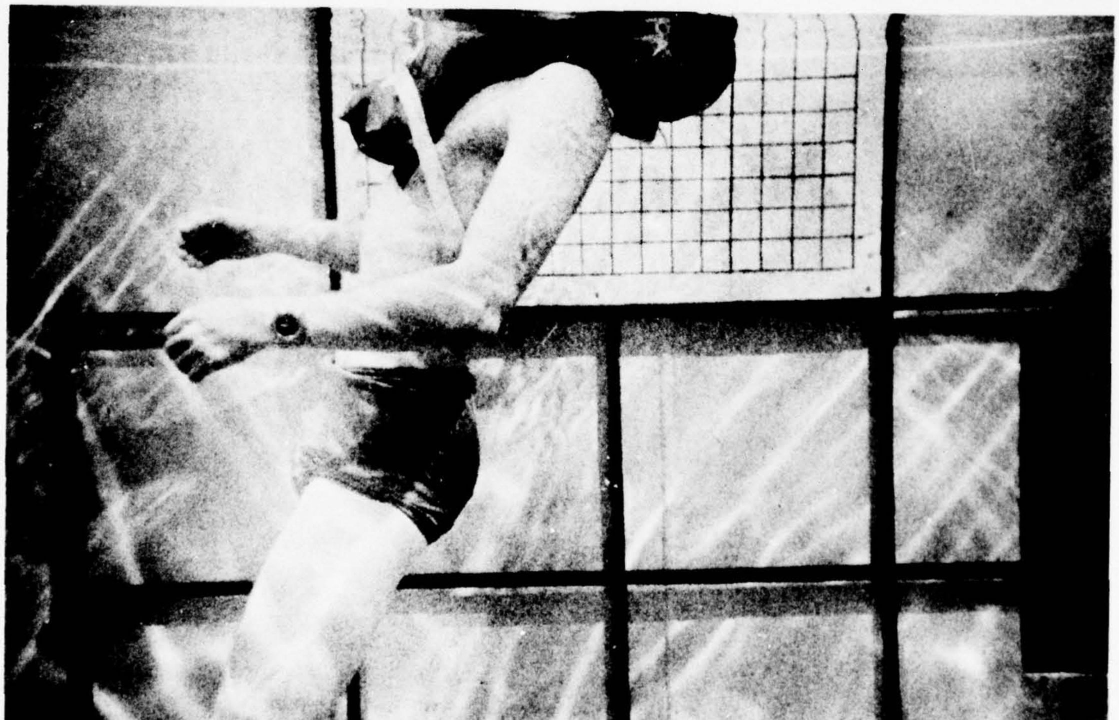
Safeguards for Human Subjects

Subjects signed a consent form which outlined the test procedure, the purpose of the experiment, and the risks involved. The Ss were told that they could withdraw from the experiment at any time. A nurse was employed to monitor S's blood pressures and general condition as well as to administer first-aid, if necessary. A person with life-saving training was on the scene at all times. The water and air temperatures were maintained at about 78° F (26°C).

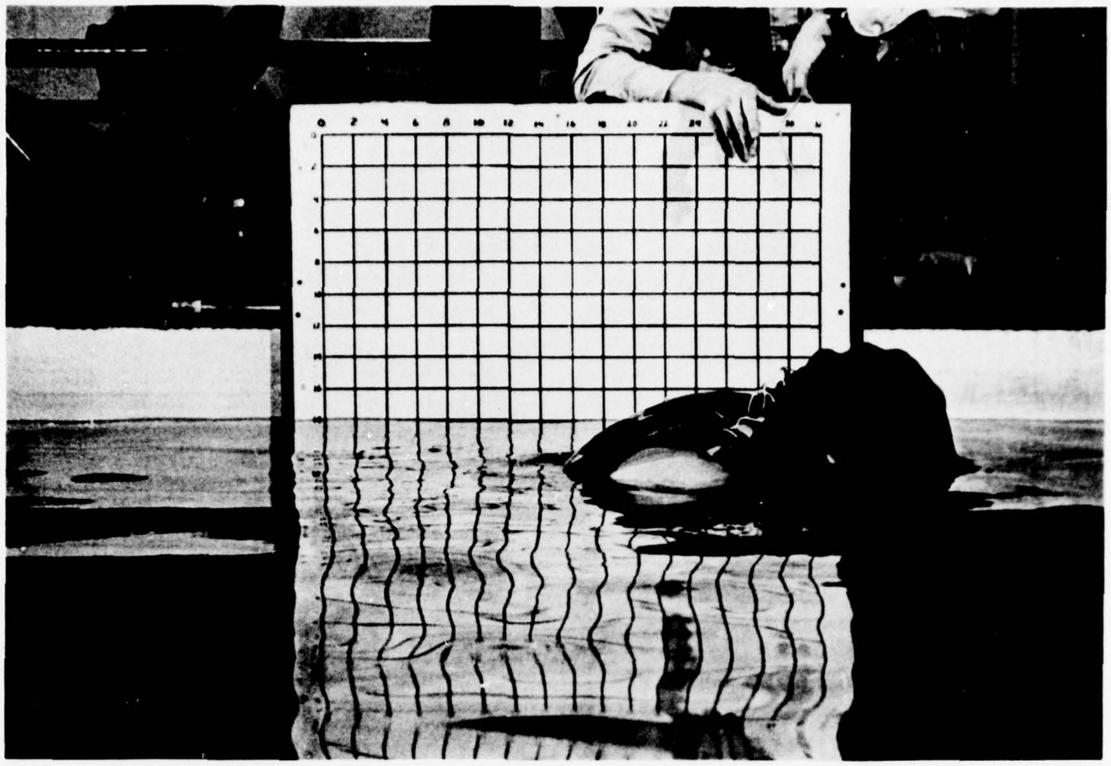
FIGURE 4-12. A TEST SUBJECT ATTEMPTING TO DON A TYPE III PFD

FIGURE 4-12A. A TEST SUBJECT ATTEMPTING TO DON A TYPE III PFD





FIGURES 4-13A (ABOVE) AND 4-13B (BELOW). MEASUREMENT OF A TEST SUBJECT'S BUOYANCY AND EQUILIBRIUM ANGLE



FIGURES 4-13C (ABOVE) AND 4-13D (BELOW). MEASUREMENT OF A TEST SUBJECT'S BUOYANCY AND EQUILIBRIUM ANGLE

4.4.2 RESULTS AND DISCUSSION

The results of the pilot investigation are presented in Tables 4-3 to 4-6 and Figures 4-14A-C. In the discussion of the results, the reader may refer to the data sheet in Appendix 4-A to keep in mind the nature of each test. The results of the wearability test are covered in Section 5.4.1 of this report.

Positions for Holding PFDs in the Water

Table 4-3 lists the various holding positions selected by Ss and summarizes the ranks assigned to each position. The positions for each type of PFD are listed in the order of their overall performance (best to worst). In general, the lower the median rank, the better the position. However, not all Ss ranked all positions. Subjects were allowed to omit a position if they considered it unsatisfactory. Thus, those positions which very few Ss used would have received much lower median ranks if all Ss had been forced to rank them. For this reason, positions which fewer than four Ss ranked are listed below the other positions. It should be remembered that the criterion for ranking the positions was ease of holding (least effort) rather than comfort. Denser Ss found Position 3 for Type II devices (see Figure 4-11C) uncomfortable because it pulled on their necks. Also, most Ss preferred to float with their head vertical or slightly forward (such that they could see what was around them) rather than in a face-up position.

The Type II turned out to be the most versatile device for holding. Subjects found more satisfactory positions for holding the Type II than the other types. Surprisingly, the Type IV was least versatile, even though it is meant to be held. All Ss found they could not hold onto the straps of the Type IV and still keep their head above water (without "donning" the Type IV as discussed later).

Three positions for holding Type II and III devices received consistently high rankings. These were the "water wings" position with the PFD held under the arms and S vertical (see Figures 4-11A and 4-11F), the "semi-donned" position (see Figures 4-11C and 4-11G), and the position with the PFD folded and held to the chest with S vertical (see Figures 4-11B and 4-11E). The latter position (PFD held to the chest) was somewhat unstable. When the PFD was

TABLE 4-3. RANKING OF POSITIONS FOR HOLDING PFDs

Description of Position	Reference Figure	No. of Times Ranked 1 or 2	Median Rank	No. of Subjects Using Position
TYPE II				
1. Held under body like water wings (face down)	2-A	3	2*	6
2. Folded, held to chest, subject face down or vertical	2-B	4	2.13	5
3. Held to chest in donned position	2-C	2	3.5	6
4. Folded, held to chest, subject on back (face up)	2-D	1	3.5	4
5. Held across chest under arms, subject on back	-	1	1	1
6. Opened, sat on	-	1	3	2
7. Folded, sat on	-	0	3.5	2
TYPE III				
1. Folded, held to chest, subject face down or vertical	2-E	5	1.5	6
2. Opened, worn like water wings, subject face down	2-F	4	2	6
3. Wrapped around body in donned position, subject on back	2-G	2	3	4
4. Opened, sat on	2-H	1	3.5	6
5. Folded, held to chest, subject on back	2-I	0	3.66	5
6. Folded, sat on	-	0	5	1
TYPE IV				
1. Held to chest, subject face down or vertical	2-J	5	1.13	5
2. Sat on	2-K	3	2.17	4
3. Held to chest, subject on back (face up)	2-L	2	2.66	5
4. Held horizontal, arms on top, subject vertical	2-M	2	2	3

* A rank of 1 = easiest position to hold PFD in; 2 = next easiest position, etc.

TABLE 4-4. EQUILIBRIUM FLOTATION ANGLE BEGINNING FROM HEAD FORWARD (HF+) AND HEAD BACK (HB-) POSITIONS

	PFD Type and Initial Position					
	II		III		IV	
Subject	HF (+)	HB (-)	HF (+)	HB (-)	HF (+)	HB (-)
Female						
1	+70	-68	+79	-71	-68	-73
2	+73	-76	+77	-67	+80 [1]	-67
3	+73	-70	+76	-58	-71	-76
Male						
4	+75	-79	+75	-63	+ [2]	-76
5	-20 [2]	-22	+74	-40	+79	-74
6	+33	-22	+55	+52	-56	-57

[1] Good photographs not available; the figure given is an estimate.

[2] This subject turned on his side with his face partially submerged.

TABLE 4-5. EQUILIBRIUM FLOTATION ANGLE WHEN THE SUBJECT ADOPTS A HUDDLED POSITION

	PFD Type		
Subject	II	III	IV
Female			
1	+61	+67	-62
2	+56	+70	-51
3	+64	+66	-42
Male			
4	-48	+68	-55
5	+73	+68	-32
6	+51	+64	-29

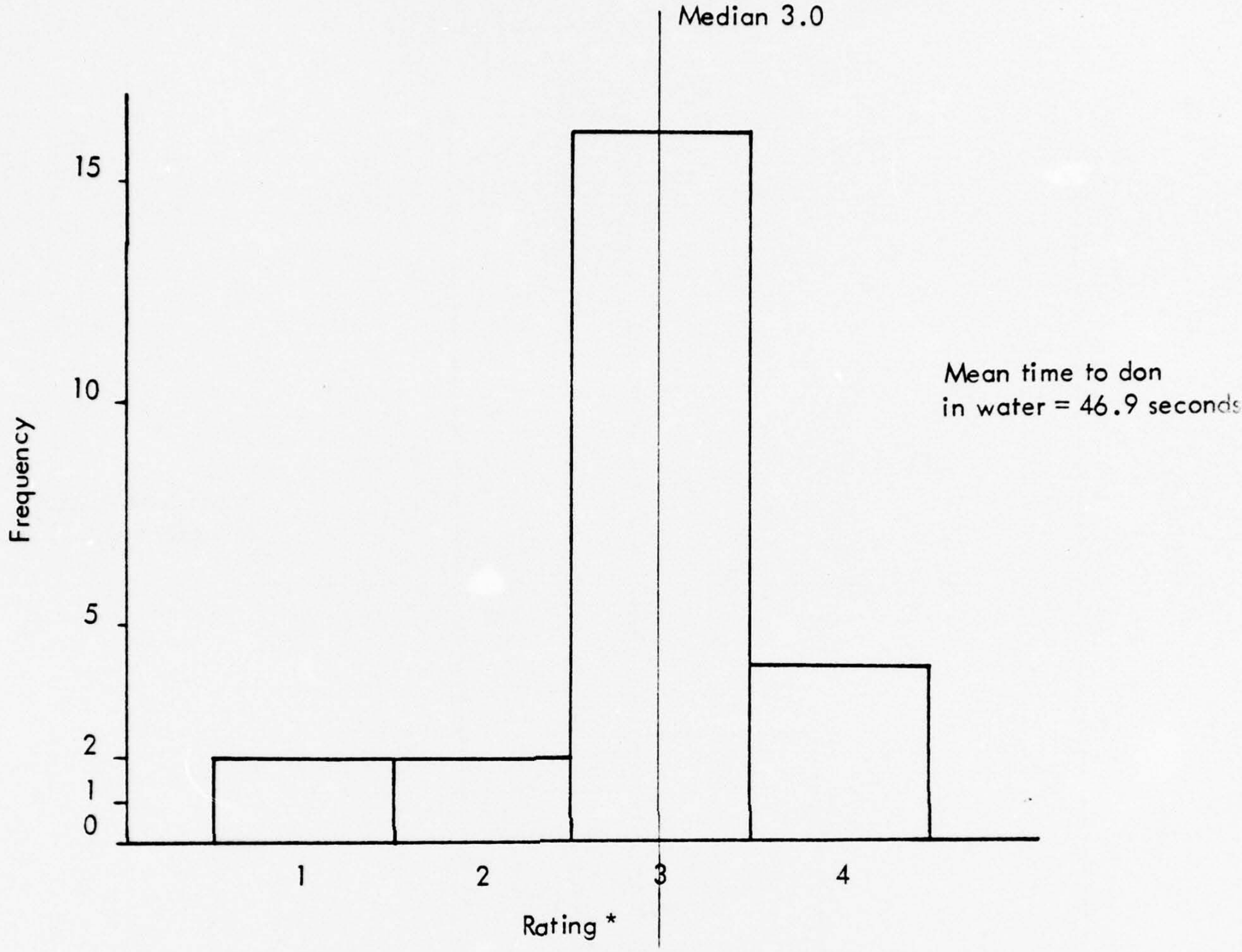
TABLE 4-6. SIGN OF EQUILIBRIUM ANGLE AFTER FALLING FORWARD (FF) OR BACKWARD (FB) INTO WATER

	PFD Type and Type of Fall					
	II		III		IV	
Subject	FF	FB	FF	FB	FF	FB
Female						
1	-	-	-	-	-(H) * -(W) *	NT
2	-	NT	-	-	-(H) -(W)	-
3	-	-	+	NT	-(H) -(W)	-
Male						
4	-	NT	+	-	+(H) -(W)	-
5	-	-	+	-	+(H) -(W)	NT
6	+	+	+	NT	-(H) -(W)	-

NOTES:

NT = No test was conducted.

* H = PFD held as the subject fell into the water.
W = PFD worn as the subject fell into the water.



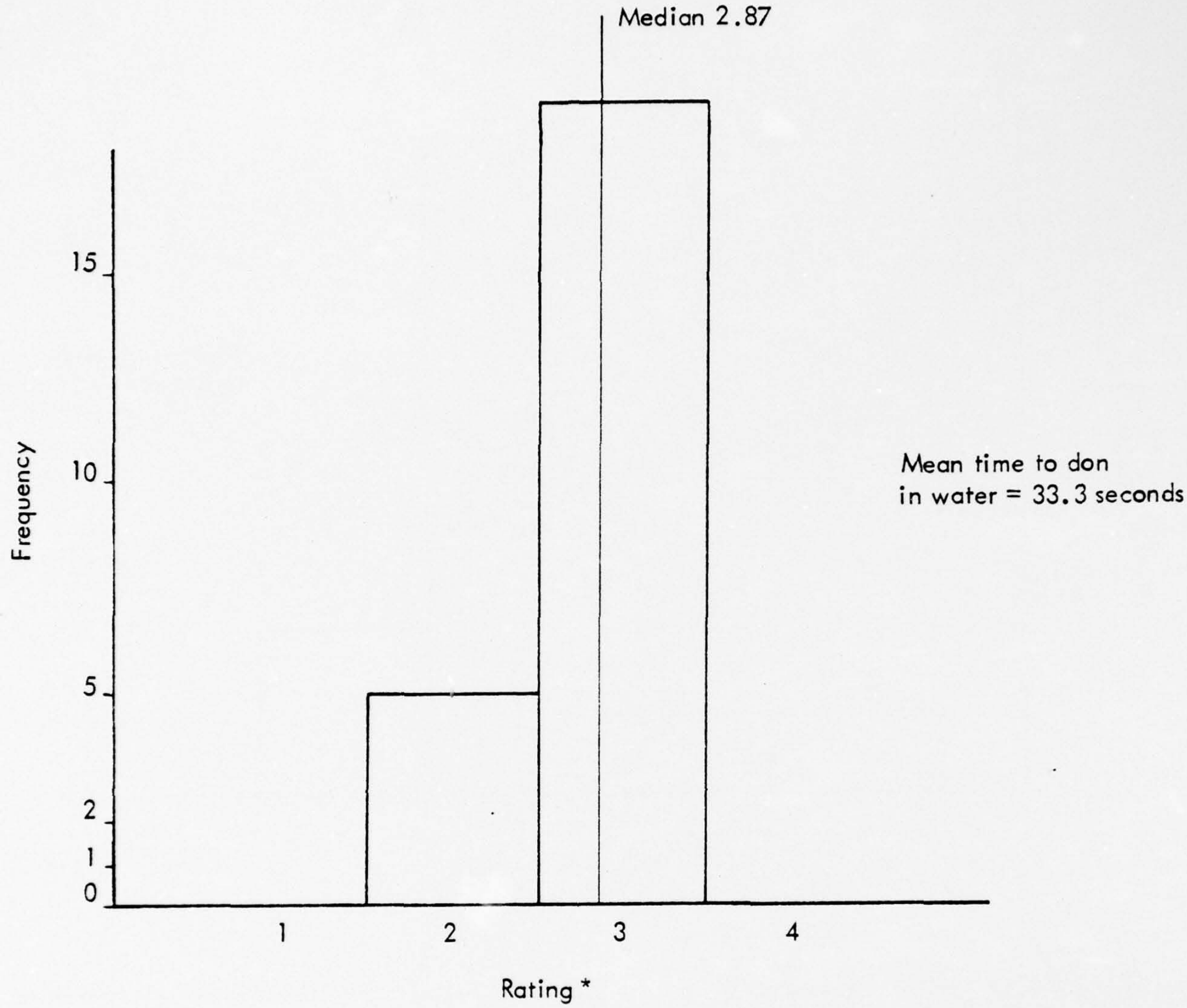
Rating Scale: * 1 - Serious difficulty - Required assistance, probably would not have been successful in rough water, had serious trouble staying afloat.

2 - Moderate difficulty - Some trouble keeping head out, trouble with fasteners or straps.

3 - Slight difficulty.

4 - No difficulty - Like a well-made jacket.

FIGURE 4-14A. RATINGS OF DEGREE OF DIFFICULTY IN DONNING PFD IN WATER (TYPE II)



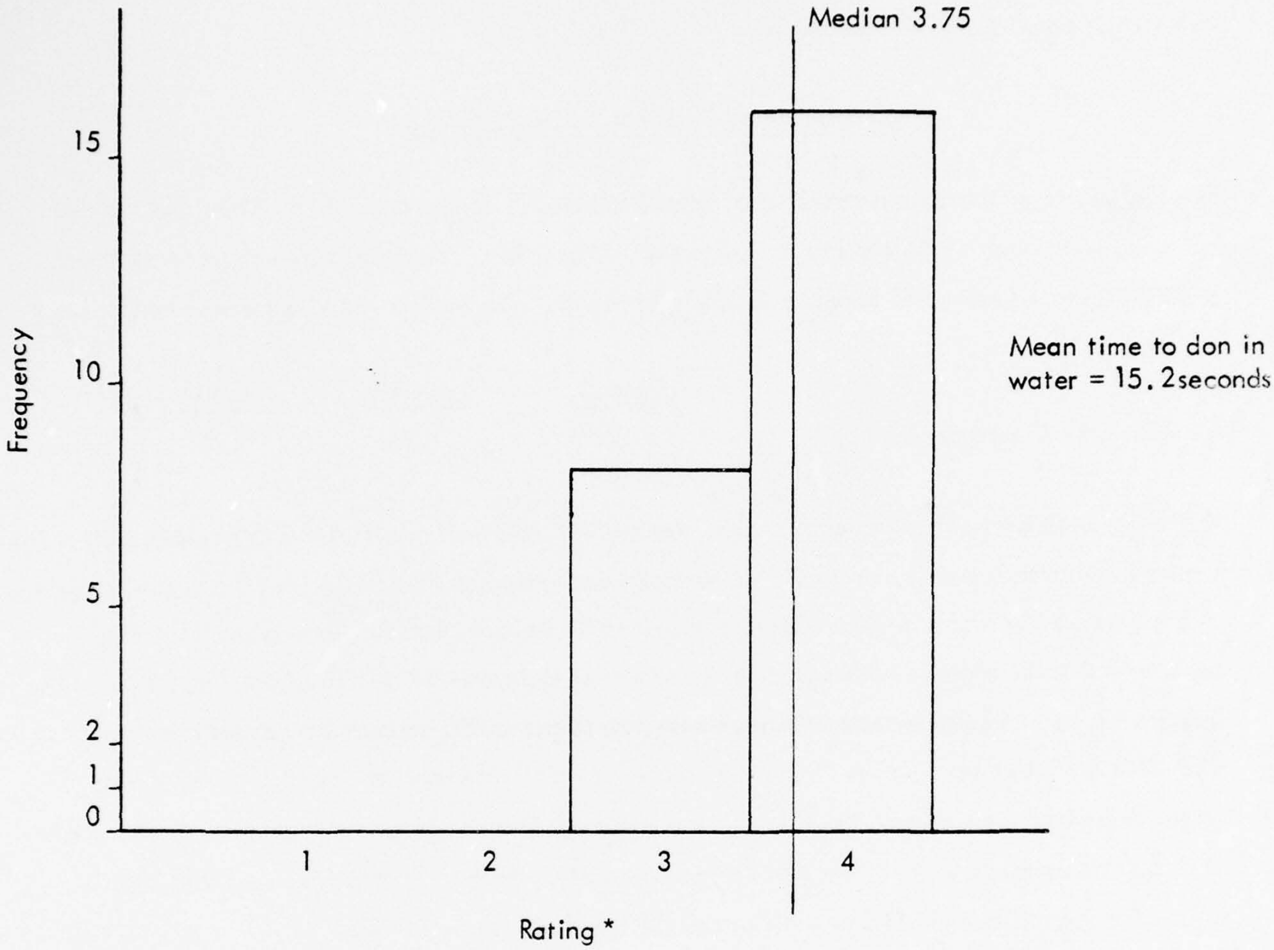
Rating Scale: * 1 - Serious difficulty - Required assistance, probably would not have been successful in rough water, had serious trouble staying afloat.

2 - Moderate difficulty - Some trouble keeping head out, trouble with fasteners or straps.

3 - Slight difficulty.

4 - No difficulty - Like a well-made jacket.

FIGURE 4-14B. RATINGS OF DEGREE OF DIFFICULTY IN DONNING PFD IN WATER (TYPE III)



Rating Scale: * 1 - Serious difficulty - Required assistance, probably would not have been successful in rough water, had serious trouble staying afloat.

2 - Moderate difficulty - Some trouble keeping head out, trouble with fasteners or straps.

3 - Slight difficulty.

4 - No difficulty - Like a well-made jacket.

FIGURE 4-14C. RATINGS OF DEGREE OF DIFFICULTY IN DONNING PFD IN WATER (TYPE IV)

held in this manner, the lighter Ss tended to turn onto their backs, in which case the PFD became much harder to hold. Those positions in which S sat on the PFD were also unstable. The sitting positions would be impractical in choppy water.

Comparison of PFDs for Ease of Holding

The last phase of the experimental procedure involved a comparison of the PFDs for ease of holding, with each PFD held in its most preferred position. Subjects ranked the three types of PFDs from 1 (easiest to hold) to 3 (most difficult). The median rankings are shown below:

	Type II	Type III	Type IV
Median Rank (based on six Ss)	1.25	1.75	2.9

The difference between the median ranks was statistically reliable ($\chi_r^2 = 6.33$, $p < 0.052$). The results show that Types II and III PFDs are much easier to hold than the Type IV buoyant cushion. In other words, the one device which is meant to be held is, in fact, harder to hold than those meant to be worn. Although this result seems to throw the utility of the Type IV cushion into doubt, one should remember that this device is generally much more accessible than wearable devices (see Section 5.3). Hence, its overall life-saving capability may be as great or greater than that of the Type II or Type III. One reason for the greater accessibility of Type IV is probably that they can be used as seat cushions. If this feature could also be built into Type II and III PFDs, their accessibility might be improved.

Donning PFDs in Water

Donning a PFD in even calm water can be extremely difficult, especially for Ss who are very dense and have little swimming ability. The S shown in Figure 4-12 experienced extreme difficulty. He went completely under several times before getting the PFD on. It seems quite possible that he might not have been successful under less favorable conditions (e.g., rough water, low water temperature, S fatigue).

Figure 4-14 shows the results of the donning test in the pilot experiment. In this test the Type IV was donned by putting one thigh through one strap and the opposite (left vs. right) arm through the other strap. For the largest male S, the straps were too small and too close together to permit donning in this manner. This S, therefore, put one arm through each strap.

Ratings showing the amount of difficulty in donning experience by each S are shown in Figure 4-14. The rating scale is shown at the bottom of the figure. The higher the rating, the easier the PFD was to don in the water. The differences among the median ratings were statistically significant ($X^2 = 9.54$, $p < .01$).

The reader will notice that Type IV devices received the highest median rating. Surprisingly, Type II devices received a slightly higher median rating than did Type III's. This difficulty seems to be due to the difficulty in getting a Type III around one's back while remaining afloat. The Type II device can, of course, simply be slipped over the head.

The mean times to done the various PFDs are also shown in Figure 4-14. Type IV's required the least time to don, the Type III the next least, and the Type II the most time. These differences were statistically significant ($F = 11.36$, $p < .05$).

The mean time required to don Type III's would have been even shorter, had it not been the case that some Ss had trouble starting the zipper. A larger zipper or other appropriate fastening device would make these devices much easier to don in the water.

Much of the time required to done the Type II device was devoted to orienting the strap and the end portions of the PFD which hold the buckle and the loop for the strap. Considerable time was also spent in getting the strap around the wearer's back.

Effect of PFDs in Swimming

Each S rated each of three types of PFDs for their effectiveness in swimming. Almost all the Ss remarked that the PFD made swimming easier in the sense that it helped keep them afloat. Some of the better swimmers remarked, however, that the PFD also slowed them down. Each PFD was given a rating from 1 through 4. A high score indicates that the PFD was helpful. (See Appendix 4-A for the rating scale.) The median ratings for each type of PFD are shown below:

	Type II	Type III	Type IV
Median Rating (based on six Ss)	4.0	3.9	3.0

The differences between these ratings were not statistically significant. There is no basis for concluding that any one PFD is any more or less helpful in swimming than another.

Equilibrium Angle and Effective Buoyancy of the PFD Wearer

In Phase VIII of the pilot experiment, Ss started in either of three positions in the water, then relaxed and allowed the PFD to turn them to whatever position it took them. Table 4-4 summarizes the final equilibrium angle of the S when he started in either a head forward or head back configuration. Note that positive angles indicate that S was leaning forward; negative angles indicate a backward posture, and zero means the centerline of the body was vertical.

When the S started in a head forward (HF) position, the Type II device failed to turn him or her to a face up position in five out of six cases. However, the Type II PFD maintained the wearer in a head back position in all cases.

The Type III devices failed to turn the wearer from the face down to head back position in all cases. In one of the six cases, the Type III failed to maintain the S in the head back position, i.e., it allowed him to turn face down in the water.

The Type IV device was the most effective in turning the wearer to head back position (three out of six cases). (In all cases, when the Type IV turned the wearer, the turn was always a roll sideways rather than to the front or back.) Like the Type II, the Type IV maintained the wearer in a head back position in all six cases.

The reader will notice in Table 4-4 that the absolute values of the equilibrium angles were generally smaller for the heavier males. This result is probably obtained because their extremities (especially legs) are denser than the water and create a moment about the center of buoyancy.

Table 4-5 shows the equilibrium angle when the S adopts a huddled position similar to that recommended for protection against hypothermia. The Type II turned the wearer to a head back position in only one out of six cases. The Type III device failed to turn the wearer in all cases. However, the Type IV in all cases turned the wearer to the head back orientation. Paradoxically, the only PFD which keeps the Ss face out of the water when he adopts a heat escape lessening posture probably provides the least body coverage.

The effective buoyancy provided by the three types of PFDs was determined by measuring the vertical distance from the base of the wearer's nose to the water level. The measurements were taken from photos of the Ss in the equilibrium positions they assumed when starting from the head-back posture. As mentioned above, the Type III allowed one S to turn face down. Omitting this case, the three types of PFDs compared as follows:

	Type II	Type III	Type IV
Average vertical distance from base of nose to water level in equilibrium position (inches)	4.9	5.4	3.5

The Type II and III devices produce comparable results (except the omitted case, of course). The Type IV, however, allows the wearer's head to fall backward so that the base of his nose is appreciably closer to the water level.

Effects of Falls on PFD Position and Wearer's Equilibrium Angle

In Phase IX of the pilot experiment, Ss were questioned as to whether the PFD changed position or rubbed against their body upon falling into the water. Two types of complaints were mentioned about Type II devices. The heaviest male S complained that the Type II rode up around his neck and felt like it was choking him. Providing a larger neck opening in the PFD would probably alleviate this problem. Several Ss mentioned that the strap on the Type II device rubbed uncomfortably against their backs. One S complained that the Type III rode up and rubbed against the side of her face. All considered, these effects seem relatively minor. Of course, falls from a higher platform could produce more serious effects.

Table 4-6 shows the sign of the equilibrium angle of the S after falling into the water. The Type II device showed the best overall performance (i.e., was most likely to turn or keep the wearer in the head back position after falls). The Type III device showed the poorest performance.

4.4.3 Conclusions

The foregoing results demonstrate that useful information about PFD physical effectiveness can be obtained through direct testing with human Ss. For example, the results of the pilot investigation show that:

- Type II devices generally fail to turn the wearer from a face-in-the-water position to the head back position.
- In some cases, Type III devices allow the wearer to turn from a head back to a face-in-the-water position. The present tests were, of course, conducted in calm water. Rough water conditions might further exacerbate the problem.
- Type IV devices were the most effective of those tested in keeping or turning Ss to a head back position. However, they allow S's head to fall backward, reducing their effectiveness.
- Type II and III devices almost always allow the wearer to turn to a face-in-the-water position when he or she adopts a huddled position similar to that recommended for protection against hypothermia.

- The Type IV buoyant cushion is the most difficult of the devices tested for Ss to hold onto in the water.
- The two best positions for holding a Type II or III device in the water are the "water-wings" position and the "semi-donned" position (see Figures 4-11A and C).
- Any of the types of PFDs tested would probably be helpful in swimming a long distance, even for highly skilled swimmers.
- The small zipper in Type III PFDs should be replaced with a larger zipper or other fastening device to facilitate donning of the device in the water.

The present results suggest that direct testing with human Ss would be a productive approach to the evaluation of PFD physical effectiveness.

4.5 DEVELOPMENT OF THE EFFECTIVENESS INDICES

As mentioned in Section 3, three types of effectiveness indices are required:

- E_W - the effectiveness of the PFD when worn
- E_H - the effectiveness of the device when held
- P_D - the probability that a boating accident victim dons the PFD in the water.

The combination of these indices in the Life Saving Index (LSI) and their application in the approval process is discussed in Section 3. The objective of this portion of the report is limited to defining the above indices in terms of parameters which can be estimated by using either the general design criteria or the test method discussed above.

The effectiveness of a PFD when worn, E_W, must encompass two types of wearers - the conscious wearer and the unconscious or seriously injured wearer. To save the latter type of wearer, the PFD must provide a turning moment to bring him or her to a vertical or face-up position in the water. For the conscious wearer, it seems reasonable to require that the PFD maintain a relaxed wearer in a vertical or face-up position. The maintenance of an upright position is important because the conscious wearer could later become unconscious or unable to control his orientation in the water due to hypothermia, shock, or exhaustion. Also, the failure to maintain the wearer in a vertical or face-up position might seriously threaten the survival possibilities for young children and victims who are disoriented or in a state of panic.

Two different methods for defining E_W will be offered. One method encompasses both conscious and unconscious or seriously injured wearers in a single index. The second method specifies separate indices for different types of PFDs. The first method assumes that the relative importance of each of the two functions which a worn PFD can perform is proportional to the percentage of cases in which that function is necessary. For example, the importance of turning a wearer to an upright position is proportional to the percentage of accident victims who are unconscious or seriously injured. The effectiveness of a PFD when worn is therefore expressed as follows:

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$$E_W = \alpha \cdot P_M + \beta \cdot P_T$$

where

α = estimated proportion of victims who are conscious when they enter the water in boating accidents

β = estimated proportion of victims who are unconscious or seriously injured when they enter the water in boating accidents

P_M = the proportion of the boating population that the PFD maintains in a vertical or face-up position in the water when relaxed

P_T = the proportion of the boating population that the PFD turns to a vertical or face-up position when unconscious or seriously injured.

The parameters α and β can be estimated from the Accident Recovery Model (ARM). The definitions of P_M and P_T must eventually specify additional boundary conditions such as the water conditions at the time of the test, the wearer's initial position, and the amount of time allowed for the PFD to turn the wearer.

One possible disadvantage of the above definition of E_W is that β will be very small. This means that the ability of the device to turn an unconscious wearer, P_T, will have relatively little impact on E_W. Under this definition, devices with very high effectiveness but low wearability might have a low overall effectiveness index.

The second method for defining E_W is similar to the current approval process in that two different types of PFDs would be approved. Devices which are highly effective in turning an unconscious wearer to the upright position could be allowed a lower wearability than devices which do not have this capability. The following definitions of E_W could be employed:

Type A Devices:

$E_{W_A} = P_T$ (Effectiveness is defined as the capability of the device to turn the unconscious wearer to a vertical or face-up position)

Type B Devices:

$E_{W_B} = P_M$ (Effectiveness is defined as the capability of the device to maintain the relaxed wearer in the vertical or face-up position.)

For Type A devices the minimum level of wearability required could be set equal to the minimum wearability of the currently approved Type II PFDs. For Type B devices, the minimum wearability would be specified as the current minimum wearability for Type III devices. This method has at least two important advantages. It would not discourage manufacturers from developing highly effective devices, even though they might have relatively low wearability. Second, it would give the boater greater freedom of choice.

The second index which must be considered is E_H, the effectiveness of the PFD when held. There are two considerations in this case:

a) that the user be able to find a position in which to hold the PFD such that he remains vertical or face-up when relaxed, and

b) that the wearer be able to hold the PFD in such a position for a long period of time.

A review of accident reports suggests that the principal cause for accident victims losing a source of flotation is that their fingers become numb. It is therefore desirable that the wearer be able to maintain himself in a upright position without grasping the PFD with his hands. These considerations suggest the following definition of the effectiveness of a PFD when held.

E_H = the proportion of the boating population for which a holding position can be found which satisfies the following criteria:

a) the PFD maintains the relaxed user in a vertical or face-up position, and

b) the position does not require that PFD be grasped with the hands.

The results of the effectiveness pilot experiment suggest that virtually all of the PFDs currently approved can satisfy this requirement for the bulk of the boating population.

The final parameter relating to effectiveness is the probability that a boating accident victim dons the PFD in the water. For currently approved devices, this parameter can be estimated from the Accident Recovery Model (ARM). For new devices, this parameter can be estimated as follows:

a) Ease of donning will be measured for both currently approved and new devices in the effectiveness experiment with human Ss. Each new device can, therefore, be placed on a dimension of "ease of donning" along with approved devices.

b) The new devices can then be placed in the same relative positions with respect to approved devices along the "probability of donning" dimension measured by ARM.

APPENDIX 4-A

PFD EFFECTIVENESS — WEARABILITY EXPERIMENT
DATA SHEET

Phase I — General Information, Health Questionnaire, and Body Measurements

Test # ________ Hours since subject last ate ____________

Date __________ Consent form completed ____________

Air Temp. ________

Water Temp. ______ PFD Control No. ____________

PFD Type: AK-1 --- Ski Vest --- Adj. Vest --- Cushion

Davey Belt --- Inflatable Vest (Circle One)

Subject's Name: ______________

Statements Regarding Health: Are you currently suffering from a cold, flu, or any other disease? __________ Do you have a history of heart disease, high blood pressure, or respiratory illness? __________ Do you know of any health-related reason why you should not participate in strenuous exercise in the water? ______________________________

Sex: Male ______ Female ______

Height ________ Leg Inseam ________ Height to suprasternal notch ________

Chin to suprasternal notch ________

Circumference of:

A. Head ________

B. Neck ________

C. Shoulders ________

D. Chest or bust ________

E. Hips ________

F. Upper thigh ________

G. Calf ________

H. Waist ________

Swimming Ability: None -- A little -- Fair -- Good (Circle One)

Do you think that you could swim the length of this tank unaided?

No -- Don't know (or maybe) -- Probably -- Easily (Circle One)

<u>Phase II — Wearability Test</u>

To the subject: Please rate this PFD on each of the following questions as you perform the indicated activity. Please use the scales shown below.

1. Subject dons and fully fastens PFD: How easy is this PFD to don and fasten (compare it to a lightweight jacket).

(Circle one number)

1	2	3	4
Very difficult (straps get tangled, zipper won't work, etc.)	bothersome	slightly annoying	easy (like a well-made jacket)

2. How would you rate this PFD on general comfort (consider weight, amount of body coverage, warmth, and ventilation.)

1	2	3	4
uncomfortable (feels tight, pinches, rubs, etc.)	annoying (feels bulky or awkward, restricts movement, rides up, etc.)	neutral (not annoying but not as comfortable as a jacket)	comfortable (like a well-made jacket)

3. Subject tries PFD in sitting and reclining positions: How do you rate this PFD on comfort while sitting and reclining:

1	2	3	4
uncomfortable (feels tight, pinches, rubs, etc.)	annoying (feels bulky or awkward, restrict movement, rides up, etc.)	neutral (not annoying but not as comfortable as a jacket)	comfortable (like a well-made jacket)

4. Subject casts fishing rod and executes paddling movements: How do you rate this PFD on freedom of movement?

1	2	3	4
uncomfortable (feels tight, pinches, rubs, etc.)	annoying (feels bulky or awkward, restricts movement, rides up, etc.)	neutral (not annoying but not as comfortable as a jacket)	comfortable (like a well-made jacket)

5. Please rate this PFD on general appearance or attractiveness (when worn).

1	2	3	4
unattractive (awkward, odd looking)	slightly unattractive	not attractive, but not objectionable in appearance.	attractive (like a well-made jacket)

Phase III — Weighing. Instruct subject to relax and remain still (subject may hold onto chair)

Dry weight (take 3 readings on body weight)

Body plus chair	Chair	Body
______, ______, ______ mv	______ mv	
______ lbs.	______ lbs	______ lbs.

Weight in water to chin. (To the subject: For this test, please take a deep breath, then exhale fully. During the test, breath as shallowly as possible and remain relaxed).

Body plus chair	Chair	Body
______ mv ______ inches	______ mv	
______ mv ______ inches		
______ mv ______ inches		
______ lbs	______ lbs	______ lbs

Phase VI — Donning PFD

To the subject: Please enter the deep end of the tank. You will be given a PFD to put on in the water. Please don the PFD as quickly as possible after I give it to you. Stay in the middle of the tank and do not touch the walls. Be sure to adjust all straps and fasten all snaps, buckles, etc.

Time __________ (secs.) The data recorder and experimenter are to rate the degree of difficulty experienced by the subject (circle one number each.) Photos ____________

Data Recorder:	1	2	3	4
	serious difficulty	moderate difficulty	slight difficulty	no difficulty
Experimenter:	1	2	3	4
	required assistance, probably would not have been successful in rough water, had serious trouble staying afloat	some trouble keeping head out, trouble with fasteners or straps		like a well-made jacket

Phase VII — Swim Test with PFD on.

To the subject: Please swim the entire length of this tank with the PFD on. Swim at a comfortable pace. You are not being timed. Do not touch the sides or bottom of the tank. Please rate this PFD on whether it helped or hindered your swimming (show this scale to the subject):

1	2	3	4
serious hindrance (seriously restricted movement)	moderate hindrance (slowed subject down)	made no difference	helped (swimming required less effort with PFD on)

Weight in water to notch.

Body plus chair	Chair	Body
________ mv ________ inches	______ mv	
________ mv ________ inches		
________ mv ________ inches		
________ lbs	______ lbs	______ lbs

<u>Phase V — PFD Holding positions and Ranking</u> (1 = Easiest position, 4 = most difficult position)

Position A: Description ____

____ Ranking ____________

Photo ____________

Position B: Description ____

____ Ranking ____________

Photo ____________

Position C: Description ____

____ Ranking ____________

Photo ____________

Position D: Description ____

____ Ranking ____________

Photo ____________

Instruct subject to hold PFD in each position for at least 30 seconds.

Phase VIII — Buoyancy and Orientation Wearing PFD

To the subject: Please adopt each of the positions described below and then let yourself go limp. Before you start each position, take a deep breath and exhale fully. During the test, breath as shallowly as possible and remain relaxed. After I tell you to go limp, please do not try to control your position in the water. Just let yourself turn to whatever position the PFD takes you.

1. Head down, forward leaning position.

Head angle: Fully back ________ (Check one) Photo______

45° back________ Photo below water line ________

Vertical________

45° forward________

Fully forward______

Water line at: Above chin_______ (check one)

Just below chin_______

Between chin and adam's apple______

At adam's apple_________

Between adam's apple and notch______

At notch_________

Below notch_________

2. Head back, backward leaning position.

Head Angle: Fully back________ (check one) Photo________

45° back________ Photo below water line________

Vertical________

45° forward________

Fully forward______

Water line at: Above chin______ (check one)

Just below chin_____

Between chin and adam's apple_____

At adam's apple______

Between adam's apple and notch_____

At notch_____

Below notch_____

3. Huddled position

Head Angle: Fully back________ (Check one) Photo_____

45° back________ Photo below water line________

Vertical________

45° forward_______

Fully forward_____

Water line at: Above chin______ (check one)

Just below chin_____

Between chin and adam's apple_____

At adam's apple_____

Between adam's apple and notch_____

At notch______

Below notch____

Phase IX — To the subject: Jump in the water (deep end) from the side of the pool, being careful not to hurt yourself or hit the edge of the pool. Once you come to the surface, please relax and allow the PFD to turn you to whatever position it takes you. As before, take a deep breath and exhale fully. Breath as shallowly as possible.

To the subject: Does the PFD feel like it changed position on your body?_________

Please describe the change, if any____

____.

Head Angle: Fully back________ (check one)

45° back________ Photo_______

Vertical________

45° forward_______ Photo below water line______

Fully forward______

Water line at: Above chin________ (check one)

Just below chin_____

Between chin and adam's apple_____

At adam's apple_______

Between adam's apple and notch_____

At notch________

Below notch_____

Phase X — Comparison of PFD's for holding

Please find the best holding position for each PFD, then hold t there for 30 sec. (the experimenter will time it for you). Then rank the PFD's according to how easy they would be to hold for a prolonged period of time. (1 = easiest, 6 = most difficult)

A. PFD type and number__________ Position______________________

______________________________________ Ranking__________

B. PFD type and number__________ Position______________________

______________________________________ Ranking__________

C. PFD type and number__________ Position______________________

______________________________________ Ranking__________

D. PFD type and number__________ Position______________________

______________________________________ Ranking__________

E. PFD type and number__________ Position______________________

______________________________________ Ranking__________

F. PFD type and number__________ Position______________________

______________________________________ Ranking__________

5.0 WEARABILITY/ACCESSIBILITY

5.1 PROBLEM DEFINITION AND BACKGROUND

The life-saving capability of PFDs depends critically upon wearability. The wearability of a PFD is defined as the probability that the PFD is worn by the victim when he enters the water in a boating accident. At the inception of this project, PFD effectiveness and reliability were believed to be reasonably high for Coast Guard approved devices. However, reports from a variety of sources suggested that the wearability of PFDs is low.

The role of PFDs in boating accidents involving fatalities was reported in Coast Guard statistics.[1] Of fatal accidents in which PFDs are known to have been on board, they were reportedly not used in 72% of the cases. In a separate review of boating accident reports, it was estimated that over 90% of drowning victims could be saved by the use of PFDs.[2]

These findings from accident reports have been corroborated by surveys of boaters in non-accident situations. The National Safety Council (NSC) conducted a nationwide mail survey of boat operators from October, 1973, through January, 1974.[3] The reported rates of PFD wear were 31% during good weather and 52% during foul weather.

Another study by Operations Research, Inc. (ORI)[4] reported somewhat lower rates of wear and found large differences between two samples. Atlanta and Miami boaters were asked to estimate the percentage of time they would wear various types of PFDs. For Atlanta respondents, the wear rate averaged over all types of wearable PFDs was 28.5%. For the Miami sample, the same figure was only 6.83%.

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[1] United States Coast Guard, Boating Statistics 1971, CG-357.

[2] Dayton, R.B., Design Criteria for Advanced PFD's, Operations Research, Inc., ORI-TR-861, 1974. NTIS No. AD-A010-404.

[3] Bryk, J.A. and Schupack, S.A., Boating Safety: The Use of Personal Flotation Devices, National Safety Council, USCG Grant No. 1301-92, 1974.

[4] Operations Research, Inc., A Study of Factors Influencing the Wearability of PFD's in Recreational and Work Environments, CG-D-88-75, 1974. NTIS No. AD-A011-211.

Both the National Safety Council and the ORI reports suffer from certain methodological faults which probably inflate the estimated wear rates. The most serious of these is that the data are self-reports; i.e., what the respondent says rather than what he actually does. The wear rates reported above may therefore be seriously overestimated.

Another problem in both of the above studies is the question of the representativeness of the sample of respondents. The NSC report surveyed only boat owners. This sample is probably older, wealthier, and contains a larger proportion of males from the population of U. S. boaters. In addition, only 49.8% of the initial sample returned questionnaires to the NSC. Those people who take the time and trouble to respond may be more cautious or conscientious people in general. In the study conducted by ORI, the Atlanta respondents were people who attended a boat show. In Miami, the respondents were boaters at a particular marina. It is possible that the large difference in wear rates between Atlanta and Miami is in part due to the particular sites sampled.

In addition to attempts to document the rate of wear of PFDs, previous research has measured various design features of PFDs and boater's attitudes.

The study by ORI mentioned earlier attempted to find design features and attitudes which were predictive of PFD wear. A questionnaire was administered to boaters at the Miami and Atlanta test sites and the results were factor-analyzed. Two factors were identified — one "person" based and another "situation" based. The person-based factor reflects consistency in respondent's answers to questions such as "I do wear or would prefer to wear a PFD at all times while boating" and "I would not be comfortable wearing a PFD." The situation based factor indicates that people who report wearing PFDs in, say, rough water also tend to report wearing PFDs under bad weather conditions. Only the person-based factor was reasonably predictive of reported wear rate. While this result is interesting, it does not help to illuminate the reasons why people wear (or don't wear) PFDs.

In the same study respondents were asked to rank PFD design parameters in importance for buying and wearing a PFD. Parameters such as effectiveness, reliability, freedom of movement and visibility were ranked highest for both buying and wearing. This result suggests that PFD

wear would be high if people thought they were effective, reliable, etc. But the wear rate is very low. Either people don't believe that Coast Guard approved PFDs are effective, reliable, and so on, or this ranking of design parameters simply is not predictive of PFD wear. This result again illustrates one pitfall of survey research — people don't necessarily report what they actually do. In the ORI study this problem was exacerbated since respondents were not given the opportunity to try the PFDs on. The report goes on to document reported preferences for PFD hue, intensity pattern, material, etc. Unfortunately, no evidence is presented that these preferences are related to PFD wearing behavior.

The threshold wearability model developed by ORI and presented in the same report was also reviewed by Wyle. The model was found to be inadequate in a number of respects.

Some of the shortcomings of the model include:

A. The model assumes that PFD properties are additive in their effect on the probability of wear.

B. The model assumes that a person can specify exactly the features of a PFD which he would wear. There may be features or combinations of features which are important, but which the person would not anticipate.

C. The model defines non-accident utility (P_{na}) as, "Probability that a PFD of a given type appeals to a given individual's esthetic sense, predictions of comfort, feeling of freedom of movement, etc." One consequence of the model is that non-accident utility is the same for all PFDs and all people.

The following definitions appear in the text:

$$P\ (\text{worn}) = P_{na}\ P_a \qquad \text{(page B-6)} \qquad (1)$$

$$P_a = P_1\ P_2\ P_3 \qquad \text{(page B-12)} \qquad (2)$$

$$P\ (\text{worn}) = P_1\ P_2 \qquad \text{(page B-13)} \qquad (3)$$

Rearranging (2) gives

$$P_3 = \frac{P_a}{P_1 \; P_2} \tag{4}$$

Equating (1) and (3) we find that:

$$P_1 \; P_2 = P_{na} \; P_a \tag{5}$$

Substituting right hand side of (5) in (4):

$$P_3 = \frac{P_a}{P_{na} \; P_a}$$

or:

$$P_3 = \frac{1}{P_{na}}$$

Since P_3 is defined as a probability (page B-12), it must take in a value between 0 and 1.0. This means that P_{na} must be 1.0 or greater. But, P_{na} is also a probability, so the only possible value of P_{na} is 1.0.

D. One of the assumptions made is inconsistent with the whole idea of developing a wearability index. The following assumption appears on Page B-13: "An inherent assumption is that the fraction of time he would wear the PFD of his choice is the same as the fraction of time he would wear any PFD." This assumption means that PFD's properties have absolutely no influence on the probability that they will be worn. If one accepts this assumption, then it is futile to worry about PFD wearability.

In another research report ORI[2] concluded that "no Coast Guard approved PFD exists that would be acceptable to the recreational boater for wearing at all times while afloat." Based on this conclusion, they recommended that advanced concepts design efforts be directed toward PFDs worn around the waist. The report also recommended inflatable PFDs to reduce weight and bulk.

5.2 PURPOSE AND APPROACH

The original purpose of this part of the PFD research project can be described as follows:

1) To determine what factors determine the wearability of PFDs and to what extent

2) To develop an index or other means of evaluating wearability for use as a regulatory tool.

Since its inception, the scope of this part of the project has been broadened to encompass PFD accessibility as well as wear. There is an increasing awareness among those who have studied PFD use that is is probably impossible (and certainly not cost effective) to get <u>all</u> boaters to wear PFDs all of the time. The recognition of this problem is implicit in the Coast Guard's approval of buoyant cushions as PFDs and in the wording of the PFD regulations, which stress that PFDs should be kept readily accessible.

One of the first problems encountered in the present work was that of defining wearability and accessibility and enumerating the factors which could influence them.

Consider the problem of defining accessibility. Where must a PFD be placed in order to be of use in an accident? The answer may depend on a variety of factors, such as the kind of accident. The minimum effective accessibility may be different for capsizings, collisions, and falls overboard. Depending on their placement, PFDs which are accessible during normal boating activity may or may not be accessible after an accident. These issues were not tackled in Phase I of this project because it was not known whether an accessible PFD can be effective. However, recently obtained results of the Accident Recovery Model (ARM) and the effectiveness portion of this project indicate that PFDs are reasonably effective when held. The issues relating to accessibility will be addressed in the next phase of this project. For the purpose of the initial studies, an accessible PFD was defined as one which is stored in any place which is not fully enclosed, i.e., on the cockpit floor, in an open shelf beneath the gunwale, etc.

The term wearability has historically been used in two different ways. When one asks "how wearable is this PFD?", he is usually referring to the design features of the PFD. In other words, wearability is more or less synonimous with comfort when used in this sense. In written contexts, however, wearability is usually defined as "the probability that a boater will be wearing a particular type of PFD immediately prior to entering the water in an accident." Wearability as defined in this second way depends not only on the design features of the PFD, but also upon the person's attitude and motivation and the environment. In fact in some environments, PFD design may have little or nothing to do with wearability as long as the PFD is perceived as effective and reliable.

The multitidue of factors that may be related to wearability can be placed in the three categories shown in Table 5-1 Characteristics of the People Involved, the Environment, and the Equipment.

Characteristics of the people on board can be further divided into individual and group factors. The individual factors are roughly divided between those which are more or less "rational" (attitudes and knowledge) and those that are "motivational" (motivation and personality). This distinction is somewhat arbitrary, but serves as a useful organizational aid. Some factors, such as a person's attitudes toward PFD's have both rational and motivational components. For example, a part of the boating population probably is unsure of the effectiveness of PFD's. This would be listed as a subfactor under "PFD Model." For the same individuals, PFDs may carry a negative connotation; i.e., having PFDs on view reminds them of the danger of drowning. This factor appears under motivational and personality factors in the table. The following paragraphs amplify and clarify some of the items in the table.

The individual's accident model includes his knowledge or misconceptions of how accidents occur. Some possible misconceptions are, "There is always sufficient warning to don a PFD in the event of an accident," or, "Most accidents occur in foul weather or crowded boating conditions." Also included under "Accident Model" is the simple awareness (or lack thereof) that boating can be dangerous.

TABLE 5-1. AN OUTLINE OF POSSIBLE FACTORS RELATED TO PFD WEARABILITY

I. Characteristics of the People Involved

- A. Individual Factors
  - 1. Attitudinal and Cognitive
    - a. Accident Model (knowledge of how accidents occur and PFD role)
    - b. Situational Model (persons opinions of conditions under which PFDs should be worn)
    - c. PFD Model (person's perception of and attitudes about PFDs)
  - 2. Motivation and Personality, e.g.
    - a. Fear of Water and Boating
    - b. Risk Taking Tendency
    - c. Emotional Connotation of PFDs
    - d. Tendency to Conform
- B. Social Factors
  - 1. Compliance, e.g., regulations, parental orders
  - 2. Identification, e.g., following an example set by parents or some other authority
  - 3. Internalization, e.g., education

II. Environmental Factors

- A. Weather
- B. Sea State
- C. Location
  - 1. Type of Body of Water
  - 2. Distance from Shore
- D. Visibility

III. Equipment

- A. Boat Size and Stability
- B. Presence of Other Safety Equipment on Board
- C. PFD
  - 1. Comfort
    - a. Bulk
    - b. Freedom of Movement
    - c. Weight
    - d. Body Coverage
    - e. Heat Retention/Cooling Properties
    - f. Quality of Surfaces Contacting Skin
    - g. Ease of Donning
  - 2. Image
    - a. Sportiness
    - b. Sex Appeal
    - c. Aesthetic Factors
  - 3. Perceived Reliability and Effectiveness

The "Situational Model" includes the boater's opinion of weather and sea conditions under which PFDs should be worn. Also included here are his opinions concerning those people who should wear PFDs (e.g., children, non-swimmers) and the types of boats on which one should wear a PFD.

The "PFD Model" covers the boater's opinions and knowledge about PFDs. For example, whether he believes they are effective, whether he regards them as emergency equipment rather than as safety equipment, whether he thinks PFDs can be donned easily in the water, etc.

The category "Motivation and Personality" factors includes relatively permanent behavioral tendencies which probably cannot be modified simply by giving the individual information. Fear of the water, for example, is usually overcome only as a result of positive experiences in water. One cannot be instructed not to fear water.

"Social Factors" refer, of course, to the influence of other people on an individual's PFD wearing behavior. This section lists three kinds of social influence which can be brought to bear upon an individual: compliance, identification, and internalization. Compliance is based on the power of the influencing agent. As soon as that power or threat is removed, the behavior in question reverts back to the original state. Regulations would fall into this category. The second level, identification, is based on the attractiveness of a model. For example, if a person has a highly respected friend who is often seen wearing a PFD, this would tend to increase PFD wear by that person. The third level of influence, internalization, is the adoption of a new belief based upon some message. The most important factor in this case is the credibility of the source of the message. A boater will generally be more likely to take the word of a seasoned sailor than a novice when he says that PFDs should be worn in certain waters.

The remaining sections of Table 5-1 list some of the environmental and equipment factors which may be associated with PFD wear. It is important to note that it is not the conditions themselves, but the person's perceptions of conditions which determine behavior. For example,

what may seem like rough seas to the Sunday boater may be only mildly challenging to the experienced sailor.

A two-fold approach to the wearability/accessibility problem has been pursued in Phase I of the present project. Section 5.3 describes an observational study of PFD accessibility and wear. The goal of this study was to obtain accurate estimates of PFD wear and accessibility. The study was designed in such a way that it eliminates or minimizes several serious methodological flaws in previous research. The observational study also identifies significant conditions in the boating environment which affect PFD use.

A second set of studies was undertaken to obtain more detailed information concerning the influence of certain variables on PFD wearability (see Section 5.4). The goal of these studies was to develop methods for predicting PFD wearability (i.e., a wearability index). The initial variables studied were mainly PFD design parameters. The results of these studies suggest that future work should be expanded to consider attitudinal and motivational factors as well.

The final section of this report on wearability/accessibility pulls together the results of the above studies and describes the development of a wearability index. The final section also offers some recommendations for further research.

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PERSONAL FLOTATION DEVICES RESEARCH. PHASE I.(U)

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5.3 OBSERVATIONAL STUDY OF PFD ACCESSIBILITY AND WEAR

A large-scale study assessed PFD wear and accessibility by direct observation at seven locations across the Continental United States. The percentage of people wearing PFDs, the number of accessible PFDs aboard, the percentage of accessible PFDs worn, and the distribution of various types of accessible PFDs were tabulated. Differences in these measures as a function of location, boating activity, age and sex of the boater, boat length and type, and type of PFD are reported. For example, the wearability of a PFD (percentage of accessible PFDs worn) depended on geographic location, air temperature and activity. The most wearable device for fishing was not the most wearable for waterskiing or other activities. The results are used to generate recommendations for educational and regulatory programs aimed at improving the life-saving capability of PFDs.

The present study departs from previous work in two important respects. First, direct data on PFD use was obtained by observing PFD use in the field. This method eliminated the problem of bias in self-reports and also improved the representativeness of the sample. The sample of people observed was not limited to operators or boat show attendees, but included all the people on board sampled boats. To further improve the representativeness of the sample, observations were taken at sixteen widely scattered sites across the continental U. S. The sample included both inland and coastal locations. The second important feature of the present study is its attention to PFD accessibility as well as wear.

5.3.1 Method

A list of sites at which observations were collected is shown in Table 5-2. In total, 995 boats and 2448 people engaged in recreational boating activities were observed and/or photographed. In addition, 33 interviews were conducted, 22 at the New York site, six at Gem Beach, Ohio, and five in San Diego. The data were collected during July and August, 1975, except for the Ft. Lauderdale and Tampa sites where the data were taken in October and March, 1975, respectively.

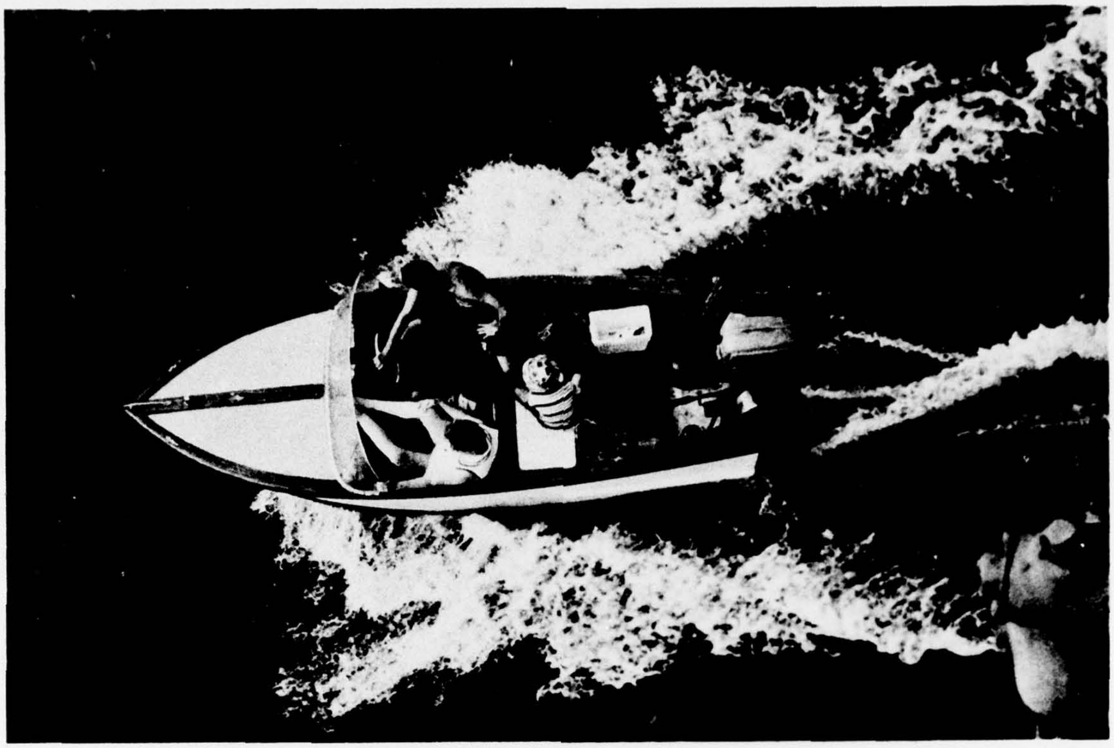
At most locations, observers worked in pairs and recorded the same boat simultaneously. One observer photographed the boat and, as time allowed, looked for the pertinent information. The other observer either spoke into a tape recorder or wrote on a standardized data form. No effort was made to select one type of boat over another for observation.

TABLE 5-2. SAMPLED LOCATIONS

Location	General Areas Sampled	No. of Boats
NE Coastal	Wareham, Massachusetts	10
	Townsend Inlet, New Jersey	17
	Bayshore, L. I., New York	170
NW Coastal	San Francisco, California	23
	Oakland, California	10
	Benicia, California	1
	Deception Pass, Washington	14
	Seattle, Washington	1
SW Coastal	San Diego, California	163
SE Coastal	Ft. Lauderdale, Florida	23
	Tampa, Florida	332
SW Inland	Lake Havasu, Arizona	77
	Lake Meade, Nevada	5
SE Inland	Guntersville Lake, Alabama	54
Great Lakes	Port Clinton, Ohio	20
	Gem Beach, Ohio	75

Photographs and observations were typically made from a low bridge or other elevated position, usually 15-40 feet above the water. Photographs were taken from directly above open boats and slightly from the stern of enclosed boats, so as to maximize visibility of the occupants and PFDs. Color slides were taken with a 35 mm camera equipped with a telescopic lens when necessary. Two examples of the observations are shown in Figure 5-1.

The interviews used a standardized form which asked about PFD preferences, attitudes related to PFD use and functioning, and the number of PFDs on board which were not in view or accessible. An effort was made to select a varied sample of persons, boat types and sizes. The questions were directed to operators and took place at marinas and launch ramps.



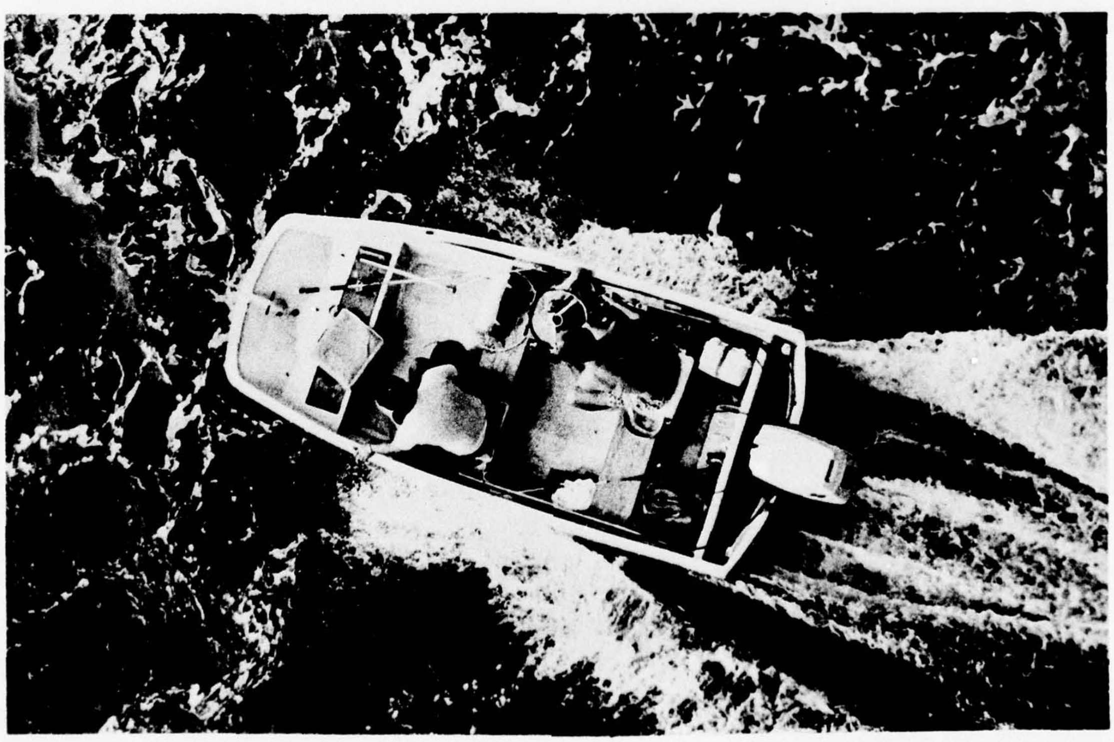


FIGURE 5-1. EXAMPLES OF OBSERVATIONS TAKEN IN THE STUDY OF PFD ACCESSIBILITY AND WEAR

Boats were classified according to type, overall length (<16 ft, ≥ 16 ft but ≤ 20 ft, and >20 ft), the apparent activity of the occupants, the age and sex of the people on board, age and sex of people wearing PFD's, type of PFD's worn, and the number and type of PFDs accessible. Note was made of non-approved as well as approved flotation aids, including ski belts, inner tubes, air mattresses, and rubber rafts.

Boats were classified under an activity even if they were not, at the moment, actively engaged in it. Since observations were generally taken from a low bridge, one would not expect to see certain activities in progress, such as water skiing. The chief evidence of activity was the equipment on board. In cases where no evidence of other activity was observed and the boat was clearly a recreational craft, the classification "pleasure cruising" was used.

Each observation was graded according to its quality. Observations for which the evaluator could be relatively confident that he saw or could have seen any accessible PFD's received a "√" mark. Observations where the rater could see the people on board well enough to determine whether they were wearing PFDs, but might have missed accessible PFDs were given an "X" mark. Other observations were discarded. Of 995 usuable observations of boats, 490 were given "√" marks. Tabulations involving PFD accessibility are based upon "√" rated observations only. Each observation was coded onto data reduction forms by a pair of trained observers working together, and was later checked by a third observer. Special attention was given to assuring that a given boat was not counted more than once and to verifying the "√" classifications.

5.3.2 Results and Discussion

Characteristics of the Boats and People Observed

Characteristics of the observed boats are presented in Table 5-3. The most frequent type of boat was the standard runabout, constituting 33% of the overall sample. The standard runabout included all boats with a closed foredeck, but no permanent superstructure above

TABLE 5-3. PERCENTAGE OF BOATS OBSERVED BY TYPE, ACTIVITY AND OVERALL LENGTH

BOAT TYPE											
House and Pontoon	Cabin Cruiser	Standard Runabout	Bowrider	Center Console Fishing	High Perfor-mance	Bass	Open Runabout	Rowboat	Johnboat	Sail	Other
1	27	33	18	5	4	1	4	1	1	3	3

ACTIVITY[b]					OVERALL LENGTH (feet)		
Fishing	Pleasure Cruising	Water Skiing	Sailing	Other[a]	< 16	16 - 20	> 20
19.5	70.4	5.3	2.3	2.6	20.5	41.5	38.0

[a] Other activities include swimming, racing, skin diving, hunting and working.
[b] The sample of 332 boats at Tampa, Florida, were photographed from such a distance and angle that it was difficult to determine activity. These cases, therefore, do not appear in this tabulation.

TABLE 5-4. PFD WEAR AS A FUNCTION OF AGE, SEX, AND TYPE OF PFD

	Percentage of Each Age and Sex Wearing Particular Types, Given That a PFD Was Worn				Percentage of Each Age and Sex Wearing Any PFD
Age and Sex	Type II Yoke AK-1	Type III Vest	Type III Jacket	Ski Belt	
Adult Male	10.5	70.2	14.0	5.3	1.5
Adult Female	50.0	39.5	5.3	5.3	3.2
Teenage Male[a]	63.6	36.4	0	0	6.0
Teenage Female[a]	77.3	22.7	0	0	11.7
Child, Male	70.0	26.7	0	3.3	38.3
Child, Female	85.2	14.8	0	0	34.5
All Persons	57.4	35.7	4.0	2.8	7.1

[a] 12-18 years of age

TABLE 5-5. PERCENTAGE OF PEOPLE OBSERVED WEARING PFDS BY LOCATION, BOAT LENGTH, TYPE AND ACTIVITY

LOCATION[a]							OVERALL BOAT LENGTH (ft)		
Southeast Inland	Northwest Coastal	Great Lakes	Southwest Inland	Southwest Coastal	Northeast Coastal	Southeast Coastal	< 16	16 - 20	> 20
22.5	9.9	8.3	7.3	5.0	4.8	3.3	9.8	9.1	4.4

BOAT TYPE				ACTIVITY			
House Pontoon Cabin Cruiser	Standard Runabout Bowrider High Performance Center Console Bass	Rowboat Johnboat Open Runabout Other < 16 Ft	Sail	Fishing	Pleasure Cruising	Skiing	Other
3.0	9.4	7.8	22.4	5.0	7.4	13.9	13.0

[a] Percentages not lying above a common line are significantly different (p < .05 or better).

gunwale other than a windshield, canvas top and frame, or moveable hard top. The next most frequent type was cabin cruisers (22%). In order to be classified as a cabin cruiser, the boat had to have a permanent superstructure other than a windshield, canvas top and frame or moveable hard top and be primarily a recreational rather than fishing or work vessel. The third ranking type of boat was bowriders (18%). It will be noticed that small, lightweight boats, including open runabouts, rowboats, and johnboats, accounted for only 6% of the sample. Tabulation of the number of boats of various lengths produced a related result. Notice that boats less than 16 feet overall length constitute only 20.5% of the sample. These figures are somewhat surprising in view of data which shows that the average length of boats sold in the United States was 14.2 feet in 1974[5]. This discrepancy may be at least partially due to differential rates of exposure for large and small craft. Another possible explanation concerns the manner in which the observation sites were chosen. Most of the sites were in major boating areas which had fairly dense boating activity. Since johnboats and other small, lightweight craft are often used for fishing and hunting, the operators may tend to avoid such areas. Indeed, it might be difficult to observe any large number of johnboats since their use tends to make them widely scattered rather than concentrated.

The distribution of boats by type differed considerably between locations. Of the boats in the northeast coastal sample, a high percentage were cabin cruisers (39%) and center-console fishing boats (10%). The northwest coastal sample was high on cabin cruisers (41%) and sailboats (22%). The locations involving small inland lakes - Lake Havasu and Guntersville Lake - were low on cabin cruisers (2% in each case). Lake Havasu, in line with its reputation, had a high percentage of high-percentage of high-performance boats (13%). Bass boats were observed only at Guntersville Lake where they formed 10% of the sample.

The distribution of boats by length also differed between locations. The inland sites had a very low incidence of boats over 20 feet long (6.8% of the boats at Lake Havasu and 7.4% of the boats at Guntersville Lake). The northwest coastal sites had the greatest percentage of boats over 20 feet (55.1%). Lake Havasu and Guntersville had high percentages of boats under 16 feet (41.9% and 31.5%, respectively).

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[5] Boating Industry Magazine, "The Boating Business, 1975," 1976.

Table 5-3 also shows the incidence of various activities. The percentage of boats fishing was remarkably similar (20-29%) for five of the locations sampled. The remaining two locations — Fort Lauderdale and Lake Havasu — showed a much smaller percentage of boats involved in fishing (4.3 and 1.2%, respectively). The percentage of boats involved in water skiing is probably underestimated due to cool and rainy weather conditions at the time of observation at many locations.

The people observed on board were categorized by age and sex. The majority of the people were adult males (56.3%). Adult females constituted only 21.6% of the total sample. Children accounted for 12.9% of the sample, and teenagers for 9.2%. The proportion of children on board varied considerably as a function of location. Fewest children were observed at the northwest coastal and southeast coastal locations; in each case, children made up about 5% of the percent of the sample. At other locations, the percentage of women on board also varied considerably, from a low of 9.2% in the northwest coastal sample to a high of 28% at Lake Havasu (southwest inland). The proportion of women and children observed seemed to be related to weather conditions.

Rate of PFD Wear

The wear rates for PFDs based on all locations are shown in Table 5-4. In these figures, each boater was weighed equally. To the extent that boater exposure by location, boat type, etc., does not correspond to the number of boaters actually sampled, these results could be slightly biased. The Wulfsberg and Lang report[6] was used to generate exposure weights for each of five geographical categories. A weighted estimate of the overall wear rate was then calculated. The weighted wear rate was 6.5%. This suggests that the unweighted wear rate of 7.1% (see Table 5-4) may be slightly overestimated. Since the exposure data are available only for very broad categories and ignore some important distinctions (such as inland versus coastal waters), it is questionable whether weighting would improve the present estimates. The present data are, therefore, presented in unweighted form.

[6] Wulfsberg, R.M. and Lang, D.A., Recreational Boating in the Continental United States in 1973: The Nationwide Boating Survey, U.S. Coast Guard, Report No. 745103, 1974. NTIS No. AD-A000-471.

Selected differences in wear rate as a function of age and sex (see Table 5-4) were tested for significance using chi-square contingency tables. Wear rate was significantly greater for adult females than adult males ($X^2 = 5.19$, $p < .05$). The wear rate did not differ for teenage males as opposed to females or male versus female children. Wear rate did vary significanly as a function of age, however. The overall wear rates for adults, teenagers, and children were 2%, 8%, and 37%, respectively ($X^2 = 484.0$, $p < .001$).

Table 5-4 also shows the rate of wear of the various types of PFDs by age and sex. The preponderance of adult males, if they wear any PFD, wear the Type III vest, but adult females wear Type II and Type III vests with almost equal frequency. This difference was highly significant ($X^2 = 16.7$, $p < .001$). The type of PFD worn also differed by age. Children were much more likely to wear Type II devices than Type III vests, but the opposite was true of adults ($X^2 = 45.5$, $p < .001$).

Table 5-5 shows the rate of PFD wear by location, boat length and type, and activity. The southeast inland location (Guntersville Lake) showed a much higher rate than the others. A later sample was taken at another lake in the southeast (Smith Lake, Alabama) for verification. The wear rate was still high, but more in line with other locations (10.5%). The differences in wear rate by location suggest the following summary statements:

- Wear rate seems to be generally higher at inland and fresh-water locations than at coastal areas.
- Wear rate tends to be higher in the midwest and west than along the eastern coast of the U. S.

PFD wear rate also varied significantly by boat type ($X^2 = 41.4$, $p < .001$). Wear rate was lowest on large power craft, intermediate for smaller, open power craft, intermediate for smaller, open power craft, and highest for sailboats.

Table 5-5 also shows the rate of PFD wear as a function of boat length. Surprisingly, the percentage of people wearing PFDs was very similar for boats less than 16 feet long and those

from 16 to 20 feet. However, wear rate was much lower in boats longer than 20 feet. The change in wear rate with length was highly significant (χ^2 = 16.2, p< 0.001). The difference in wear rate from boats less than 20 feet long to those greater than 20 feet would have been even greater if sailboats had not been included in the sample. The change in wear rate from boats less than 16 feet to the two larger categories was most pronounced for teenage males (13.7% versus 2.2%).

The percentage of people wearing PFDs also changed with activity. The rate of PFD wear is lowest (5%) for fishing, intermediate (7.4%) for pleasure cruising and highest (13.9%) for skiing (χ^2 = 11.4, p <.01). It should be noted that the sample of skiers is made up entirely of people in the boat as opposed to on skis.

PFD Accessibility

Table 5-6 shows the number of boats which met certain criteria of PFD accessibility. Coast Guard regulations specify that boats under 16 feet long shall have at least one approved PFD accessible for each person on board. Coast Guard approved buoyant cushions (Type IV — throwable) may serve as PFDs in this class. Boats of 16 feet length or greater must have at least one wearable approved PFD "readily accessible" for each person on board plus at least one approved throwable "immediately available." It is apparent that many boaters ignore the admonition to keep PFDs accessible. The picture is even gloomier if one considers only throwables (Type IV). Only 28% of the boats had at least one Type IV accessible.

Those locations which had the highest rates of wear also showed the highest accessibility. There was a strong association between wear rate and the proportion of boats having at least as many approved PFDs available as people on board (by location, r_s = 0.679, p < .05). However, this was not true for Type IVs. The location which showed the lowest percentage of boats with at least one Type IV accessible. In fact, the correlation between PFD wear and having at least one Type IV accessible for the seven locations was very near zero (r_s = 0.04).

TABLE 5-6. PERCENTAGE OF BOATS MEETING CERTAIN CRITERIA OF PFD ACCESSIBILITY BY BOAT TYPE, SIZE AND ACTIVITY

	Percentage of boats which had accessible:			
	At least one:		At least as many devices as people on board:	
BOAT TYPE	Approved PFD	Type IV (Throwable)	Approved PFD	Type I, II or III (Wearable)
House Pontoon Cabin Cruiser	53.5	39.4	14.1	6.2
Standard Runabout Bowrider High Performance Center Console Bass	57.5	20.7	19.0	11.0
Rowboat Johnboat Open Runabout Other < 16 Ft.	64.2	41.5	54.7	24.5
Sail	83.3	33.3	50.0	50.0
BOAT OVERALL LENGTH (Ft)				
< 16	58.1	29.6	32.4	16.4
16 - 20	60.2	21.8	21.8	13.3
> 20	53.0	35.1	14.6	6.6
ACTIVITY				
Fishing	62.4	33.6	32.0	13.6
Pleasure Cruising	54.4	25.6	19.3	12.3
Skiing	93.5	35.5	12.9	0.0
Other	33.3	16.7	22.2	9.7
ALL BOATS	57.6	28.0	22.2	12.0

TABLE 5-7. NUMBER OF PFDS ACCESSIBLE AND PERCENTAGE OF THESE PFDS WORN BY LOCATION

	Type of PFD						
Location	Ski Belt	Type II Yoke AK-1	Type III Vest	Type III Jacket	Number of Boats	% of People on Board w/Wearable PFD Accessible	% of People on Board With a PFD Accessible
NE Coastal	1 (0)	52 (32.7)	9 (44.4)	0 -	141	14.3	28.2
NW Coastal	0 -	2 (0)	10 (90)	3 (100)	18	27.3	41.8
SW Coastal	2 (0)	58 (25.9)	13 (38.5)	4 (50)	110	21.6	31.7
SE Coastal	0 -	7 (0)	0 -	0 -	23	15.9	27.3
SW Inland	5 (40)	29 (48.3)	29 (10.3)	0 -	57	29.0	35.9
SE Inland	4 (50)	58 (39.7)	16 (87.5)	0 -	54	40.2	43.3
Great Lakes	2 (50)	61 (34.4)	9 (22.2)	0 -	87	26.5	44.5
TOTAL	14 (35.7)	267 (33.7)	86 (43.0)	7 (71.4)	490	23.8	35.2

NOTE: *Any PFD's over and above the number of people on board a boat were not counted.*

The number of boats with at least one Type IV accessible varied considerably for different types of boats. The category of open rowboats, johnboats, etc., and the category of house-boats, pontoon boats and cabin cruisers were both high in comparison with the category of standard runabouts, bowriders, etc. These differences were highly significant ($X^2 = 20.98$, $p<0.005$). It may be that standard runabouts, bowriders, etc., are neither small and unstable enough to cause the owner to carry a throwable, nor large enough to make life rings seem appropriate.

Another significant relationship in Table 5-6 involves the number of boats with at least as many approved PFDs accessible as people on board. Small, lightweight boats show a much higher rate of accessibility (54.7%) than do the larger power craft (14.1% and 19%). This relationship is highly significant ($X^2 = 39.57$, $p<0.005$). This difference may be due to the instability of small boats, or may reflect the fact that the smaller craft are open and have fewer "inaccessible" places for PFDs. A related difference appears with boat length. The percentage of boats with a sufficient number of approved PFDs accessible decreases as length increases, going from 32.4% for boats under 16 feet to 14.6% for boats over 20 feet long ($X^2 = 12.2$, $p<0.01$).

PFD accessibility also depends on activity. The percentage of boats with at least one approved PFD accessible is much higher for skiing than other activities ($X^2 = 11.16$, $p<0.005$). The percentage of boats with at least one Type IV accessible did not differ significantly for the various activities ($X^2 = 3.66$, $p>.05$). Interestingly, the number of boats having sufficient approved PFDs on board was highest for fishing and lowest for skiing ($X^2 = 10.02$, $p<.01$). These results suggest that skiers may tend to use PFDs only for skiing as opposed to general use on board the boat. Thus, skiers tend to have accessible only one or two PFDs, while fishermen are more likely to have a sufficient number of PFDs accessible for all the people aboard.

Table 5-7 shows the number of PFDs accessible by type and the proportion of accessible PFDs which are worn. The top entry in each cell represents the number of PFDs accessible. The lower figures in parentheses are the percentages of accessible PFDs worn.

The percentage of accessible PFDs worn can be used as a rough measure of PFD wearability (which presumably reflects PFD comfort, attractiveness, etc.). From Table 5-7 it is evident that the wearability of various types of PFDs differed markedly with location. At the southeast inland location, Type III vests showed a higher wearability than did Type II's or ski belts ($\chi^2 = 9.6$, $p<0.01$). However, the reverse was true at the southwest inland site ($\chi^2 = 10$, $p<.01$). Wearability for Type II's and vests did not differ significantly at the Great Lakes, northeast coastal, and southwest coastal locations. At other locations, the number of accessible PFDs observed was too small to permit any conclusions. These results suggest that PFD wearability depends upon the conditions. The Type III vest is probably more comfortable under most conditions. However, under extremely hot conditions, such as those at the southwest inland location, the Type II with its smaller body coverage may be preferable.

Table 5-7 also shows the percentage of people on board with a PFD accessible for each location. As observed before, there is a high correlation between PFD accessibility and the percentage of people wearing PFDs at each location ($r_s = 0.89$, $p<0.05$).

Table 5-8 shows the tabulation of wearability and accessibility as a function of boat type, length, and activity. There were no significant differences in the wearability of various types of PFDs as a function of boat type. However, the percentage of people with a PFD accessible differed significantly with boat type ($\chi^2 = 41.17$, $p<.005$). Sailboats and the category of small, lightweight boats showed roughly twice the PFD accessibility of larger power craft.

For boats under 16 feet and for boats from 16 to 20 feet, the wearability of Type III vests was greater than that of Type IIs. Data from these two categories of boat lengths were pooled. Using pooled figures, the wearability of vests (52%) was significantly greater than that of Type IIs (33%; $\chi^2 = 7.5$, $p<0.01$). However, for boats over 20 feet long, the wearability of Type IIs (36%) exceeded that of vests (15%; $\chi^2 = 3.22$, $0.10>p>0.05$). These results must be interpreted with caution. Large boats obviously have inaccessible places where PFDs can be stored out of sight of the observers. If a disproportionately large number of Type IIs are stored in these areas, the comparative wearability for Type IIs and vest on boats over 20 feet could be distored. However, the reader will notice that the wearability of

TABLE 5-8. NUMBER OF PFDS ACCESSIBLE AND PERCENTAGE OF THESE PFDS WORN BY BOAT TYPE, LENGTH AND ACTIVITY

	Type of PFD					
Boat Type	Ski Belt	Type II Yoke AK-1	Type III Vest	Type III Jacket	% of People on Board w/Wearable PFD Accessible	% of People on Board With a PFD Accessible
Houseboat	2	55	12	0	16.2	29.7
Pontoon	(0)	(29.1)	(25)	-		
Cabin Cruiser						
Standard Runabout	11	180	66	2	25.8	34.4
Bowrider	(36.7)	(37.2)	(42.4)	(0)		
High Performance						
Center Console						
Bass						
Rowboat	1	30	3	2	30.5	59.3
Johnboat	(100)	(23.3)	(33.3)	(100)		
Open Runabout						
Other < 16 Ft						
Sail	0	1	5	3	56.3	62.5
	-	(0)	(100)	(100)		
Boat Length (Ft)						
< 16	3	70	11	2	24.5	40.7
	(33.3)	(35.7)	(54.5)	(100)		
16 - 20	8	139	55	1	28.3	35.8
	(37.5)	(31.7)	(50.9)	(0)		
> 20	3	58	20	4	16.9	30.4
	(33.3)	(36.2)	(15)	(75)		
Activity						
Fishing	1	48	11	1	23.3	47.3
	(100)	(12.5)	(63.6)	(0)		
Pleasure Cruising	6	193	56	6	22.9	31.7
	(33.3)	(36.3)	(39.3)	(83.3)		
Skiing	7	25	14	0	34.6	45.1
	(28.6)	(56)	(21.4)	-		
Other	0	1	5	0	15.8	21.1
	-	(0)	(100)	-		

NOTE: Any PFD's over and above the number of people on board a boat were not counted.

TABLE 5-9. ESTIMATED NUMBER OF PFDS ACCESSIBLE OR ON BOARD PER BOAT

Measure	Ski Belt	Type II Yoke AK-1	Type III Vest	Type III Jacket	Type IV Throwables
PFD's Accessible					
Observations *	.015	.506	.092	.012	.559
Interviews	.182	2.939	.030	0.000	.667
PFD's On Board					
Interviews	.303	6.303	1.000	.394	1.515

* These figures are the averages for the same three locations for which interview data was available.

vests drops from 52% for boats less than 20 feet long to 15% for boats greater than 20 feet ($X^2 = 8.34$, $p<0.01$). Thus, there is an apparent change in wearability of vests with boat length.

The percentage of people on board with a PFD accessible was inversely related to boat length, going from a high of 40.7% for boats less than 16 feet long to 30.4% for boats greater than 20 feet ($X^2 = 9.72$, $p<0.01$).

For fishermen, the wearability of vests was dramatically higher than that of Type IIs ($X^2 = 10.36$, $p<0.01$). In contrast, wearability was higher for Type IIs than for vests for skiers ($X^2 = 4.35$, $p<0.05$). This result is particularly surprising when one considers that skiers were much more likely to have vests accessible than were fishermen. For skiers, 30% of the available PFDs were vests; but for fishermen only 18% of the accessible PFDs were vests. For pleasure cruising, wearability of yokes and vests did not differ significantly. Clearly, the wearability of various PFDs depends upon the activity in which the boater happens to be engaged. Further research will be required to specify the exact characteristics of each activity which influence wearability.

The percentage of people on board with a PFD accessible also differed as a function of activity. Fishing and skiing showed highest accessibility while people pleasure cruising were less likely to have a PFD accessible ($X^2 = 28.45$, $p<0.005$).

Table 5-7 also shows the relative accessibility of Type IIs and vests. Overall, Type IIs made up 71.4% of the accessible wearable PFDs; vests accounted for only 23%. Lake Havasu (southwest inland) had the highest accessibility of vests (46% of the wearable PFDs), while the Great Lakes and northeast coastal locations had the smallest percentage of vests (14.5% and 12.5%, respectively).

Table 5-8 shows the variation in relative accessibility as a function of boat type. Vests made up the largest portion of the PFD population for the category of standard runabouts, etc. Small, lightweight boats had the lowest availability of vests, and house, pontoon boats and cabin cruisers were intermediate ($X^2 = 6.51$, $p<0.05$). Relative accessibility did not differ significantly with activity.

Interview Data

Table 5-9 summarizes the reported number of PFDs on board and the number of PFDs which interview subjects reportedly keep accessible on a normal outing. It should be emphasized that the interview data are all self-reports and, therefore, subject to distortion. For example, interviewees report that on the average nearly three Type IIs are kept accessible per boat. However, observations of boats reveal only 50 Type IIs accessible per 100 boats. The number of PFDs reportedly on board may be similarly distorted. If the reported number of PFDs aboard is taken at face value, then only a small proportion of PFDs are kept accessible. For vests and Type IIs, for example, the number of accessible PFDs is only 1/11-1/12 of those reportedly on board.

Table 5-10 shows reported preference. The solid construction foam ski vest was ranked highest. Surprisingly, the AK-1 ranked second in preference. The high ranking given AK-1s may be due to the subject's lack of experience with other types of PFDs.

TABLE 5-10. PFD PREFERENCE

Rank (1=Most Preferred)	PFD Type
1	Ski Vest, solid construction, belted (Type III)
2	AK-1, standard canvas covered (Type II)
3	Hinged Vest with Zipper (Type III)
4	Buoyant Jacket (Type III)
5	Kapok-filled Canvas Work Vest (Type I)
6	Inflatable Jacket (Not Approved)
7	Vinyl Covered Foam Yoke (Type I)
8	Featherlight (Type III)

5.3.3 Conclusions

The present study assessed PFD accessibility and wear by directly observing recreational boaters underway in seven regions of the continental United States. The overall percentage of boaters wearing PFDs was very low (7.1%). The low wear rate is not surprising in view of boaters' attitudes about PFDs. Interviews indicated that most boaters believe that PFD wear is necessary only under extreme conditions (e.g., rough water), for children, and in a few cases for non-swimmers. As yet, boating safety courses and Coast Guard publications and films have done little to combat these attitudes in those that were interviewed. A systematic evaluation of the boating safety media is urgently needed.

An additional reason for the low wear rate may be PFD discomfort and expense. Boaters frequently complained that Type II PFDs are too bulky, hot, etc. On the other hand, Type III devices are too expensive, according to boaters' reports.

A third factor which may contribute to the low wear rate is motivation. The boater on a typical outing probably does not anticipate entering the water. In those activities where entering the water is more likely, PFD wear is higher. Sailboats and boats involved in skiing show exceptionally high rates of wear.

One would also expect the PFD wear rate to be higher in smaller, less stable boats. This prediction was only partially supported. Wear rate was inversely related to boat length, but the differences were not dramatic. On the other hand, the category of "rowboats, johnboats, etc." which are often under 16 feet showed a slightly lower wear rate than the category of standard runabouts, bowriders, etc.

The fact that wear rate differed widely between locations (a high of 22.5% versus a low of 3.3%) suggests that PFD-wearing behavior may be reasonably maleable.

The accessibility data show that a sizeable proportion of the boats over 16 feet long (73%) do not have at least one Type IV device accessible as required by the Coast Guard. The data also show that 42.4% of the boats observed had no approved PFD of any kind accessible.

Although PFD accessibility in general is correlated with wear, availability of Type IV devices was not associated with wear. This result suggests that some boaters who do not wear PFDs nonetheless keep a Type IV accessible. If this is the case, it may prove easier to increase PFD accessibility than wear.

Comparing Tables 5-5 and -8, it is evident that PFD wear is strongly associated with the percentage of people on board with an approved PFD accessible. Some noticeable exceptions to this rule are the activity of fishing and the category of "rowboats, johnboats, etc." These two categories are near or below the mean on PFD wear, but well above the mean on PFD accessibility. Of course, these two categories overlap considerably, i.e., many fishermen use small, lightweight boats. The reason for the discrepancy between the levels of wear and availability for these categories may be related to the necessity for freedom of movement in fishing. This would make wear of the standard Type II, which constitutes most of the PFD population, low. At the same time, fishermen often use small, relatively unstable boats and must lead them to keep PFDs highly accessible. Incidently, the present argument also suggests that wearability of vests should be much higher than that of Type IIs for fishermen. This was indeed the case as discussed below.

The most important conclusion about PFD wearability is that it is relative to the conditions. The results show that wearability of vests is greater than that of Type IIs for fishermen, but the opposite is true for skiers. Similarly, in hot locations like Lake Havasu, wearability of Type IIs was greater than that of vests, while in more temperate climates like Guntersville Lake, the reverse occurred. The relative wearability of Type IIs and vests also changed as a function of boat length. The results suggest that many variables influence wearability, and that the relative weight of these variables depends on the conditions.

As expected, the results show that most of the accessible PFDs were Type IIs as opposed to Type III vests. Vests were particularly scarce on boats less than 16 feet long, on small, lightweight boats, and in certain locations. Vests were frequent on boats involved in skiing, and at the Lake Havasu location. The fact that size and type of boat influences the accessibility of vests may reflect the high cost of these PFDs. The overall low frequency of vests relative to Type IIs could also be due in part to boat dealers' retailing practices. Dealers

generally sell boats as a complete system including a "Coast Guard Safety Package" (i.e., PFDs). In order to keep the price as low as possible, dealers normally include only Type II PFDs. An educational program in this area could encourage dealers to offer alternative safety packages.

The foregoing results have amply demonstrated the feasibility and value of a direct observational approach to PFD wearability and use. This technique avoids the biases inherent in survey and self-report methods. The method of direct observation used in this study revealed unexpected relationships and interactions of PFD use with other variables which probably would not have been discovered through a survey approach.

5.4 PILOT STUDIES OF PFD WEARABILITY

Although the observational method discussed in the previous study has many advantages, it does not allow a detailed analysis of how selected variables affect PFD wearability. Therefore, two additional pilot studies were conducted. In these studies, respondents were asked to rate various PFDs on a number of dimensions. Steps were taken wherever possible to insure that the results accurately reflect of PFD preferences and attitudes in the boating population. Respondents always wore the PFDs they were rating and, where possible, the ratings were taken in the context of recreational boating activity. The main purpose of these studies was to develop a background and methodology for further research. Most of the dimensions examined in the pilot studies were related to PFD design parameters since they would be easy to modify by regulation and it was felt that they would exert a great influence on PFD wear.

An additional goal in the present studies was to collect information on differences in PFD preferences and attitudes among various populations. The development of an effective wearability index requires that non-approved and experimental PFDs be evaluated for wearability. Naturally, there are certain legal and ethical problems in distributing such devices to the public. Information was therefore gathered from a sample of Wyle employees and a sample of U. S. Coast Guard personnel (BOSDETS) as well as the public in order to determine whether these groups could act as a stand-in for the public.

5.4.1 Pilot Study I

Additional wearability data was collected in conjunction with a recent pilot experiment on PFD effectiveness (see section 4.4 of this report for details of the method). Each of six subjects rated Type II (AK-1) and Type III (buoyancy vest) PFDs on each of five dimensions. The rating scales employed are shown in Table 5-11. Subjects assigned each PFD a rating from 1 to 4 in each dimension. In all cases, the higher the rating, the more wearable the PFD. The results are shown in Table 5-12.

Surprisingly, Type II and III devices did not differ significantly on ease of donning and fastening out of the water. The wearability test was the S's first encounter with the Type II device in the experiment, so it seems unlikely that the lack of difference could be due to practice.

The Type III devices were rated superior to Type II's in general comfort and appearance and attractiveness. The most frequent complaint about Type IIs was the feeling of bulk around the neck and on the chest which they produced. Some S's also complained about the bulkiness of Type IIIs. These comments suggest that inflatable devices, which could be made very flat around the neck and chest, may achieve much higher wearability.

TABLE 5-11. WEARABILITY RATING SCALES FOR STUDY I

To the subject: Please rate this PFD on each of the following questions as you perform the indicated activity. Please use the scales shown below.

1. Subject dons and fully fastens PFD: How easy is this PFD to don and fasten (compare it to a lightweight jacket).

(Circle one number)

1	2	3	4
Very difficult (straps get tangled, zipper won't work, etc.)	bothersome	slightly annoying	easy (like a well-made jacket)

2. How would you rate this PFD on general comfort (consider weight, amount of body coverage, warmth, and ventilation.)

1	2	3	4
uncomfortable (feels tight, pinches, rubs, etc.)	*annoying* (feels bulky or awkward, restricts movement, rides up, etc.)	*neutral* (not annoying but not as comfortable as a jacket)	comfortable (like a well-made jacket)

3. Subject tries PFD in sitting and reclining positions: How do you rate this PFD on comfort while sitting and reclining:

1	2	3	4
uncomfortable (feels tight, pinches, rubs, etc.)	annoying (feels bulky or awkward, restrict movement, rides up, etc.)	neutral (not annoying but not as comfortable as a jacket)	comfortable (like a well-made jacket)

4. Subject casts fishing rod and executes paddling movements: How do you rate this PFD on freedom of movement?

1	2	3	4
uncomfortable (feels tight, pinches, rubs, etc.)	annoying (feels bulky or awkward, restricts movement, rides up, etc.)	neutral (not annoying but not as comfortable as a jacket)	comfortable (like a well-made jacket)

5. Please rate this PFD on general appearance or attractiveness (when worn).

1	2	3	4
unattractive (awkward, odd looking)	slightly unattractive	not attractive, but not objectionable in appearance.	attractive (like a well-made jacket)

TABLE 5-12. MEDIAN WEARABILITY RATINGS
FOR STUDY I

Scale	PFD Type II	PFD Type III	Significance Level
1. Donning and fastening (out of water)	3.25*	3.5	NS
2. General comfort	2.0	2.9	p = .03125
3. Comfort in sitting position	1.83	2.5	NS
4. Freedom of movement	2.17	2.17	NS
5. Appearance and attractiveness	1.1	2.9	p = .0625

* The higher the score, the more favorable the rating.

FIGURE 5-2. PFDs USED IN WEARABILITY STUDY II

From top left: ERO model 6320; Davy Belt (from Mail Boat, Inc., Ft. Lauderdale, FL); Stearns Sans Souci II model SSV-165; AK-1; and Cypress Gardens model AV-2.

5.4.2 Pilot Study II

5.4.2.1 Method

PFDs were distributed to each of three groups — the public, Wyle employees, and personnel of the USCG BOSDET detachment in Florence, Alabama. Subjects were sent or given a pair of PFDs along with explicit instructions. They were asked to answer a questionnaire concerning each PFD both before and after wearing the PFD during the normal boating activities. The instructions are shown in Appendix 5-A.

The public group was made up of friends of Wyle employees. They were selected so as to obtain a cross section of geographical areas and types of boating activity. The sampled included 9 men and 3 women. Two of the subjects were from California, six from Florida, two from Alabama, and two from Tennessee. By activity, six subjects engaged in pleasure cruising, two were fishing, two canoeing, and two sailing. In the Wyle group, there were eight men and five women. Four subjects were engaged in pleasure cruising, two were fishing, two canoeing, three sailing, and two water skiing. All the Wyle subjects boated in northern Alabama. The BOSDET subjects were all males and were engaged in safety patrols.

In so far as possible, the PFDs were distributed such that each would be evaluated in the context of every other PFD equally often. Members of the public group received only one pair of PFDs. Subjects in the Wyle and BOSDET groups each evaluated two pairs of PFDs. Only one pair of PFDs was evaluated on any given outing. The distribution of PFDs was controlled such that no subject evaluated the same PFD twice, and each PFD was evaluated equally often in the first and second round of ratings by the Wyle and BOSDET groups.

The PFDs used in the present study are shown in Figure 5-2. The public group used only the Coast Guard approved types. The Wyle and BOSDET groups used the Davy Belt in addition to the approved types.

In order to insure the subjects' safety, a cautionary message was added to the instructions (see Appendix 5-A). In addition, a special informational and consent form was distributed to participants using the Davey Belt (Appendix 5-B). The form was worded so as to inform the

FIGURE 5-2. PFDs USED IN WEARABILITY STUDY II

From top left: ERO model 6320; Davy Belt (from Mail Boat, Inc., Ft. Lauderdale, FL); Stearns Sans Souci II model SSV-165; AK-1; and Cypress Gardens model AV-2.

subjects of the status and operational characteristics of the Davy Belt while biasing the subjects' attitudes toward the device as little as possible.

The questionnaire is shown in Appendix 5-C. The top portion concerns the characteristics of the subject, the boat, and the environment in which the PFD was worn. Part 2 of the questionnaire contains 32 questions concerning various aspects of PFDs. A five point Likert scale was used so that the subject could indicate his degree of agreement or disagreement with each question.

The questions were designed to probe eight different dimensions which may be related to PFD wearability. The dimensions and the list of questions comprising each are shown in Table 5-13. The convenience dimension refers to the usefulness of the PFD outside its primary use. The "image" dimension taps the boater's feelings about wearing a PFD and the emotional connotation of PFDs. For example, does the PFD make him feel safer, or does it connote the possibility of trouble? Does the boater feel that wearing a PFD makes him look like a more or less competent boater?

TABLE 5-13. DIMENSIONS OF PFD FUNCTIONING AND ASSOCIATED QUESTIONS USED FOR WEARABILITY STUDY II

Dimension	Questions
Cost	17. This PFD is probably relative inexpensive compared to other PFDs.
	31. This PFD probably costs over $20 (retail).
Appearance	2. The color and/or pattern of the coverying on this PFD is very attractive. (Rate preferred side if reversible).
	3. The shape of this PFD is odd and would look strange on a person.
	5. This PFD does not detract from the appearance of the person who wears it.
	28. This PFD looks awkward and unattractive on on most people.
Comfort	4. This PFD does not rub, scrape, or pinch the wearer's skin.
	6. This PFD would help keep the wearer warm in cool weather.
	7. This PFD is not excessively hot or sweaty in warm weather.
	8. This PFD feels bulky and uncomfortable when worn.
	9. This PFD does not restrict my movement or get in my way during boating activities.
	10. This PFD fits snugly all around, but not too tightly.
	11. This PFD tends to ride up or otherwise be uncomfortable when the wearer is in a sitting or reclining position.
	20. This PFD would be reasonably comfortable to wear for hours at a time.
	29. Wearing this PFD would seriously interfere with my normal activities while boating.
	30. This PFD provides about the right amount of body coverage for my boating activities.

Dimension	Questions
Convenience	12. The pockets (if any) on this PFD are useful and convenient.
	32. This PFD can be conveniently used as a cushion to sit or recline on.
Perceived Effectiveness and Reliability	13. This PFD looks like it would be highly effective under normal conditions in keeping the wearer's head out of the water so that he could breathe.
	14. This PFD looks like it would work well even in very rough water.
	15. In a harsh boating environment, this PFD might deteriorate quickly to the point where it would malfunction.
	16. In a boating emergency I'd probably be better off without any PFD than with this PFD.
Wearability and Accessibility	18. If I had a PFD of this type available, I would wear it most or all of the time while boating.
	19. I would probably wear this PFD only in very rough conditions.
	21. If this were the only type of PFD aboard my boat, I would insist that non-swimmers and young children wear one.
	22. If this were the only type of PFD aboard my boat, I would insist that all my passengers wear one.
	24. If I had only this type of PFD aboard my boat, I would keep several out in the open so they would be accessible in case of an emergency.
Image[1]	23. The experienced boater would probably not wear this PFD under normal conditions.
	25. If I kept PFDs of this type lying out in the open aboard my boat, experienced boaters or friends would probably think I was being over-cautious.
	26. If inexperienced passengers saw PFDs of this type lying around a boat, they might think the operator was expecting trouble.

Dimension	Questions
Image	27. *If inexperienced passengers saw PFDs of this type lying around a boat, they would probably feel safer.*
Ease In Donning	1. This PFD is easy to don and fasten.

[1] See text for explanation.

5.4.2.2 Results

Median ratings were computed for each PFD, each group, and each dimension both before and after wear. The results are shown in Figures 5-4(a) through 5-4(d).

Consider first the results for the public group. Figure 5-4(a) shows the median ratings for wearability/accessibility and comfort. The light-colored bars represent the before-wear ratings and the dark bars represent the after-wear data. Comparisons among PFDs were always based upon the after-wear data. Note that that the ERO device received the highest wearability rating and the AK-1 the lowest. This difference was statistically reliable ($p = 0.053$). There were no significant differences in wearability among the ERO, Cypress Gardens, and Stearns devices.

On the comfort dimension, the Stearns device ranked highest and the AK-1 was lowest. Several participants remarked that the Stearns device was better tailored and provided a more comfortable fit. Statistical analysis showed that both the AK-1 and the Cypress Gardens were rated significantly less comfortable than the Stearns device. The difference between the AK-1 and the ERO, however, was not significant. The low ratings given the Cypress Gardens device may be related to a complaint offered by several participants. They commented that, when in a sitting position, the device rode up and rubbed against their chins and necks.

Figure 5-4(b) shows the results for the image and appearance dimensions. Looking again at the public group, one sees little difference between the PFDs on the image variable. The image dimension, it will be recalled, taps the boater's feelings about wearing the PFD, e.g., does it make him look like a more or less competent boater, does it make him feel safer or less safe? One would expect the AK-1 to receive a low image rating due to its awkward appearance, but this difference did not materialize.

The ratings for appearance were as expected. The AK-1 was rated significantly lower than any of the other devices used by the public group ($p \leq 0.008$). There were no significant differences among the ERO, Cypress Gardens, and Stearns PFDs.

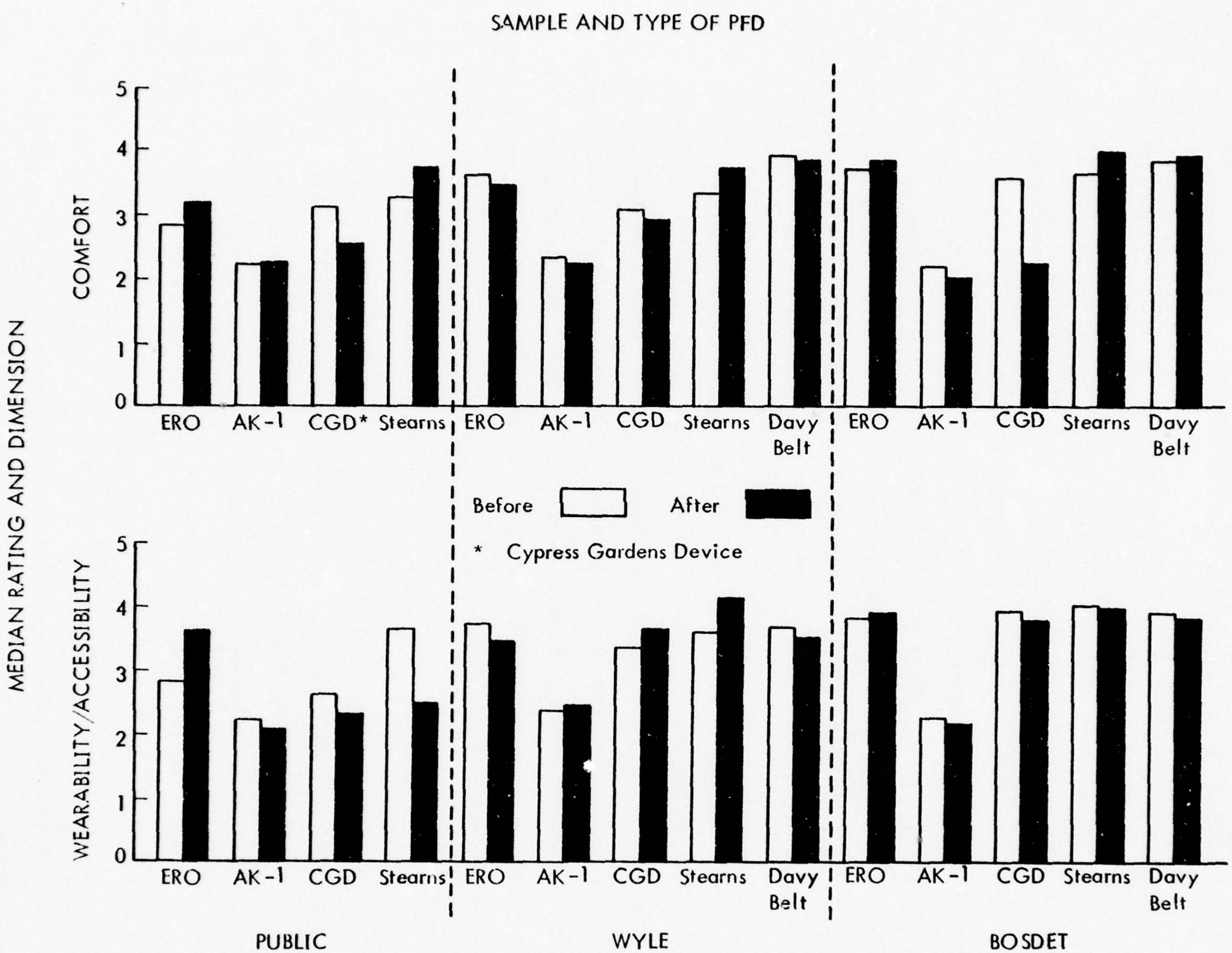

FIGURE 5-4(A). MEDIAN RATINGS FOR WEARABILITY STUDY II

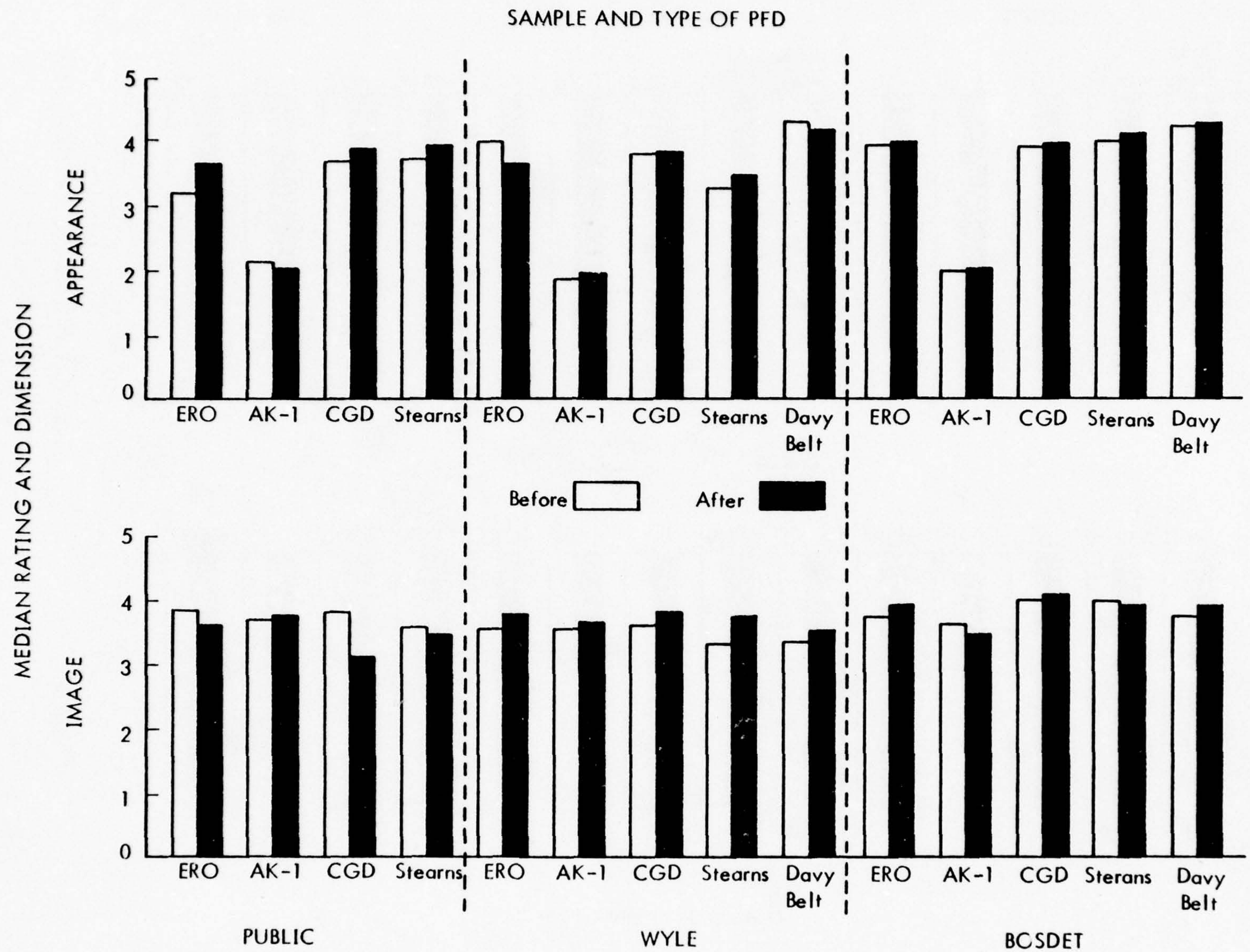

FIGURE 5-4(B). MEDIAN RATINGS FOR WEARABILITY STUDY II

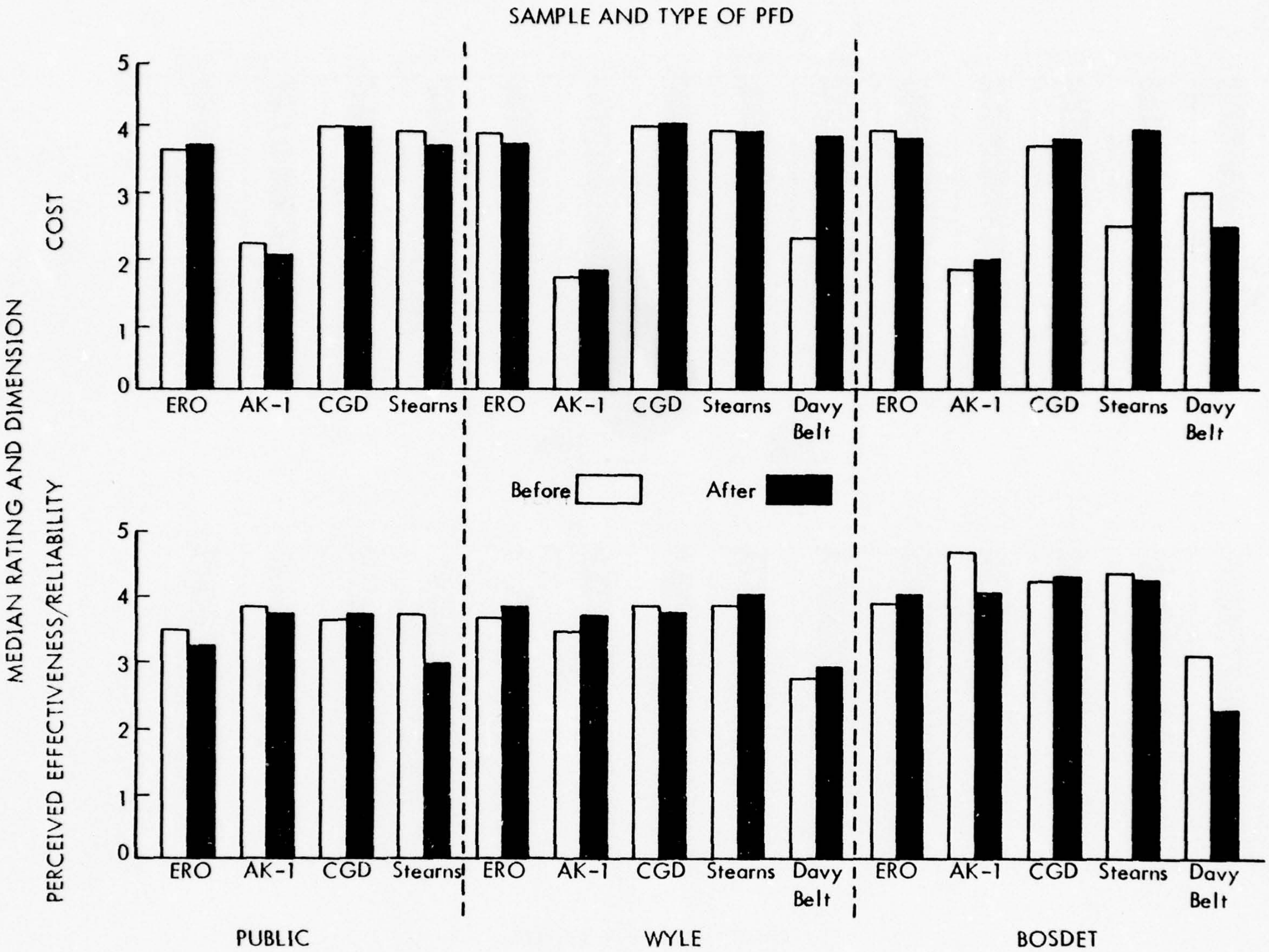

FIGURE 5-4(C). MEDIAN RATINGS FOR WEARABILITY STUDY II

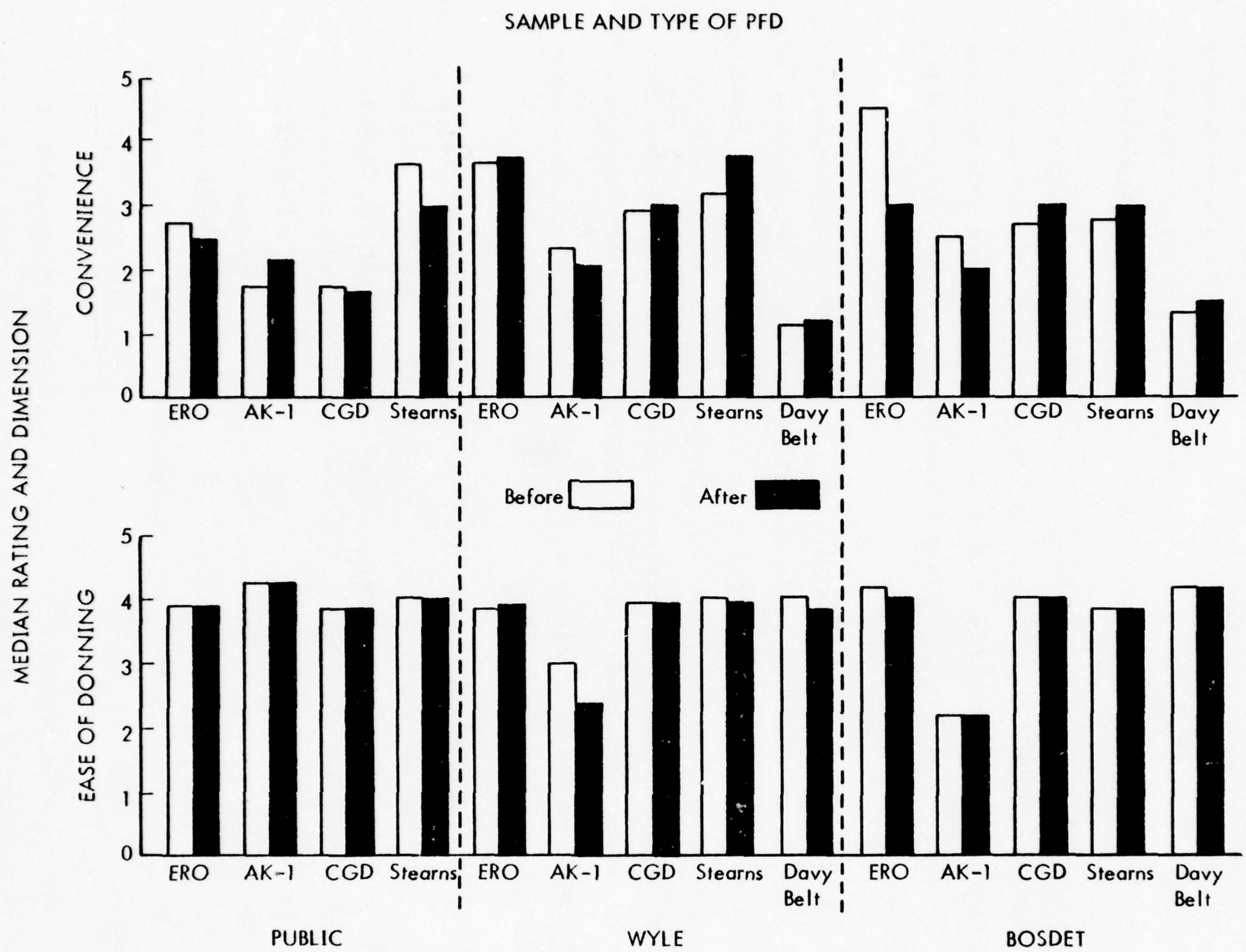

FIGURE 5-4(D). MEDIAN RATINGS FOR WEARABILITY STUDY II

The median ratings for perceived effectiveness/reliability and cost are shown in Figure 5-4(c). There were no statistically reliable differences in perceived effectiveness/reliability among the PFDs used by the public group. On the cost dimension, the AK-1 was rated significantly lower than the ERO, Cypress Gardens, and Stearns, all of which received very similar ratings.

The last figure 5-4(d) shows the results for ease of donning and convenience. Suprisingly, the AK-1 received the highest rating on ease of donning. Ratings for the other devices used by the public group on this dimension were slightly but not significantly lower. On the convenience dimension, there were reasonably large differences between devices, but none of these differences were statistically significant.

One of the questions of interest in the present study was the effect of extended wearing of the device on boaters' attitudes toward it. For the public group, the most interesting before-after difference occurred for the Stearns and ERO devices on Wearability/Accessibility and for the Stearns on Perceived Effectiveness/Reliability. On Wearability/Accessibility the Stearns, in particular, showed a large decrease. However, none of the before-after differences even approached statistical significance. There is no evidence to conclude that wearing these PFDs for several hours, as opposed to simply trying them on, changed boaters' attitudes on any of the eight dimensions.

In the present study it was anticipated that the Davy Belt device would be superior to approved devices on dimensions such as comfort, appearance, image, and wearability. These differences did not materialize. Consider the after-wear ratings in Figure 5-4(a-d). The Davy Belt was comparable to the ERO, Cypress Gardens, and Stearns devices on all dimensions except perceived effectiveness/reliabilty and convenience. Comparing after-wear ratings in the Wyle group, the Davy Belt was rated significantly lower in perceived effectiveness/reliability than any other device ($p \leq 0.02$). The questions making up the convenience dimension were not particularly appropriate to the Davy Belt. This fact probably accounts for its low ratings on this dimension.

Another objective of the present study was to determine whether the various samples of subjects produce similar ratings. If no significant differences are observed among the groups, one can be more confident that results produced by the Wyle or BOSDETS group can be generalized to

the public. Perusing Figures 5-4(a)-(d), the only striking differences one observes are on the Ease of Donning and Wearability/Accessibility dimensions. In Figure 5-4(d) note that the public group rates the AK-1 easiest to don, while the Wyle and BOSDET groups rate the same device hardest to don. This difference, although large, was not statistically reliable. On the Wearability/Accessibility dimension, the Cypress Gardens and Stearns devices received higher ratings in the Wyle and BOSDETS groups than in the public group. However, the same pattern of statistically significant differences emerged in all groups. The AK-1 was rated lower than the ERO, Cypress Gardens, and Stearns, which did not differ. This comparison of the median ratings reveals little difference between the groups. However, we have not yet examined the relationships among the variables.

Another goal of this project is to find variables which are related to or predictive of PFD wearability. It is therefore important to consider the extent to which the various dimensions are correlated with Wearability/Accessibility and one another.

Intercorrelations were computed for all possible pairs of dimensions for each group. The intercorrelations were based on the after-wear ratings only. The results are shown in Tables 5-14(a) through 5-14(c). For the reader who is unfamiliar with the correlation measure, it should be noted that the range of possible value of the correlation coefficient is -1.0 to +1.0. A correlation of zero, or near zero, indicates no association between the variables concerned. A positive correlation indicates a direct relationship and a negative correlation signifies an inverse relationship. The greater the absolute value of the correlation, the stronger the association between the variables concerned. For the public group (see Table 5-14a) the strongest correlation was that between Comfort and Perceived Effectiveness/Reliability. The correlation is -0.64. This indicates a moderately strong inverse relationship between these dimensions. The less comfortable devices, such as the AK-1, tend to be perceived as more effective and reliable than more comfortable devices such as the Stearns and ERO PFDs. There was also a direct association between PFD appearance and wearability/accessibility and between PFD appearance and rated cost in the public group.

TABLE 5-14(a). INTERCORRELATIONS BETWEEN DIMENSIONS FOR THE PUBLIC GROUP USING AFTER-WEAR DATA (N=24)

	Ease of Donning	Image	Wearability/ Accessibility	Perceived Effectiveness/ Reliability	Convenience	Comfort	Appearance
Cost	-0.23	-0.20	0.28	-0.14	0.00	-0.02	0.54*
Appearance	-0.19	-0.32	0.52*	-0.33	0.15	0.07	
Comfort	0.11	-0.31	-0.18	-0.64*	0.31		
Convenience	0.13	-0.27	-0.14	-0.31			
Perceived Effectiveness and Reliability	0.03	-0.03	-0.24				
Wearability/ Accessibility	-0.21	0.22					
Image	-0.04						

* Significant at the $p < 0.01$ level or better.

TABLE 5-14(b). INTERCORRELATIONS BETWEEN DIMENSIONS FOR THE WYLE GROUP USING AFTER-WEAR DATA (N=42)

	Ease of Donning	Image	Wearability/ Accessibility	Perceived Effectiveness/ Reliability	Convenience	Comfort	Appearance
Cost	0.30	-0.09	0.42*	-0.05	0.22	0.48*	0.60*
Appearance	0.37	0.01	0.49*	-0.44*	0.03	0.50*	
Comfort	0.31	0.05	-0.02	0.02	0.14		
Convenience	-0.09	0.07	0.00	0.32			
Perceived Effectiveness and Reliability	-0.02	0.49*	0.21				
Wearability/ Accessibility	0.03	0.32					
Image	-0.26						

* Significant at the $p < 0.01$ level or better.

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TABLE 5-14(c). INTERCORRELATIONS BETWEEN DIMENSIONS FOR THE BOSDET GROUP USING AFTER-WEAR DATA (N=17)

	Ease of Donning	Image	Wearability/ Accessibility	Perceived Effectiveness/ Reliability	Convenience	Comfort	Appearance
Cost	0.47	0.56	0.15	0.27	0.58	-0.16	0.53
Appearance	0.78*	0.47	-0.07	-0.24	0.29	-0.39	
Comfort	0.52	-0.07	0.60	-0.39	0.11		
Convenience	-0.05	0.33	0.03	0.20			
Perceived Effectiveness and Reliability	-0.35	0.20	-0.32				
Wearability/ Accessibility	0.52	0.23					
Image	0.52						

* Significant at the $p < 0.01$ level or better.

The pattern of intercorrelations was somewhat different for the Wyle group (see Table 5-14b). There was no association between comfort and perceived effectiveness/reliability (r = 0.02). However, as was the case with the public group, correlations between appearance and wearability/accessibility (r = 0.52) and cost and appearance (r = 0.54) were relatively strong. There were certain other interrelationships which were significant for the Wyle group but not for the public group (see Tables 5-14 (a) and (b)). Statistical tests were conducted to determine whether these interrelationships differed significantly for the public and Wyle groups. The results are shown in Table 5-15. The most important differences are the intercorrelations for comfort and perceived effectiveness/reliability and image and perceived effectiveness/reliability. These differences highlight important areas where results of the Wyle group cannot be generalized to the boating public.

Selected comparisons were also made between intercorrelations for the BOSDET and public groups. These results are shown in Table 5-16. The correlation between appearance and ease of donning was significantly higher in the BOSDET group than in the public group.

The most important interrelationships in the present study are those between the various dimensions and wearability/accessibility. These associations provide the means for predicting wearability and establishing a wearability index. Intercorrelations of each of the other dimensions with wearability/accessibility are shown in Table 5-17. Both the Wyle and BOSDET groups were examined to determine which produced intercorrelations most closely resembling those of the public group. The BOSDET intercorrelations differed significantly from those of the public group in three out of seven comparisons. For example, PFD appearance was directly related to reported wearability for the public sample (r = 0.52) but virtually unrelated for the BOSDET sample (r = -0.07). On the other hand, comfort and ease of donning were strongly related to wearability for the BOSDETS (r = 0.60, 0.52) but inversely related for the public group (r = - 0.18, -0.21). None of the seven intercorrelations for the Wyle group differed significantly from those of the public group. These results strongly suggest that the Wyle sample is much better predicter of PFD wearability for the boating public than is the BOSDET sample.

TABLE 5-15. COMPARISON OF INTERCORRELATIONS BETWEEN SELECTED DIMENSIONS FOR THE PUBLIC AND BOSDET GROUPS

CORRELATED DIMENSIONS	GROUP		Tests of Differences Between Correlations and Fisher "Z" Statistic	
	PUBLIC N=24	BOSDET N=17		
1. Appearance and Ease of Donning	-0.19	0.78	-3.59	**
2. Appearance and Wearability/Accessibility	0.52	-0.07	1.87	NS
3. Comfort and perceived effectiveness/reliability	-0.64	-0.39	-1.00	NS

** $p < 0.01$ NS No significant difference

TABLE 5-16. COMPARISON OF INTERCORRELATIONS BETWEEN SELECTED DIMENSIONS FOR THE PUBLIC AND WYLE GROUPS

CORRELATED DIMENSIONS	GROUP		Tests of Differences Between Correlations and Fisher "Z" Statistic	
	PUBLIC N=24	WYLE N=42		
1. Comfort and perceived effectiveness/reliability	-0.64	0.02	-2.87	**
2. Cost and wearability/accessibility	0.28	0.42	-0.59	NS
3. Cost and comfort	-0.02	0.48	-2.00	*
4. Appearance and comfort	0.07	0.50	-1.77	NS
5. Perceived effectiveness/reliability and image	-0.03	0.49	-2.09	*

NS No significant difference; * $p < 0.05$; ** $p < 0.01$

TABLE 5-17. INTERRELATIONS OF VARIOUS DIMENSIONS WITH WEAR/ACCESSIBILITY AND TESTS OF SIGNIFICANCE BETWEEN CORRELATIONS

DIMENSION CORRELATED WITH WEAR/ACCESSIBILITY	GROUP			Tests of Differences Between Correlations and Fisher "Z" Statistic	
	BOSDET N=17	WYLE N=42	PUBLIC N=24	BOSDETS vs. PUBLIC	WYLE vs. PUBLIC
Cost	0.15	0.42	0.28	-1.15 NS	0.59 NS
Appearance	-0.07	0.49	0.52	-5.43**	-0.15 NS
Comfort	0.60	-0.02	-0.18	7.35**	-0.60 NS
Convenience	0.03	0.00	-0.14	1.44 NS	-0.52 NS
Perceived Effectiveness and Reliability	-0.32	0.21	-0.24	-0.25 NS	1.69 NS
Image	0.23	0.32	0.22	0.09 NS	0.40 NS
Donability	0.52	0.03	-0.21	6.63**	0.90 NS

NS No significant difference

** Significant difference at the $p < 0.01$ level or better.

Multiple correlations were computed to determine which variables best predict wearability/ accessibility for each group. The square of the correlation coefficient (R^2) is a measure of the efficiency of with which certain independent variables can predict a dependent variable (in this case wearability/accessibility). The quantity R^2 is the proportion of variance in the dependent variable which is "accounted for" or related to the independent variables. For example, in the public sample the correlation between wearability/accessibility and appearance is:

$$r = 0.52.$$

Since

$$r^2 = 0.27,$$

27% of the variance in wearability/accessibility is due to or can be explained by differences in appearance. In this example, appearance was the only independent variable. In some cases, using additional independent variables increases one's ability to predict the dependent variable. For the public sample the combination of variables which best predicts wearability/ accessibility is appearance and image. In this case, using additional variables did not result in a significant increase in predictive power. The multiple correlation between wearability/ accessibility and appearance and image is:

$$R = 0.66.$$

Since

$$R^2 = 0.44,$$

44% of the variance in wearability/accessibility is due to or can be explained by differences in appearance and image. Considering the small sample of Ss ($N = 11$) used and the fact that this was only a pilot study, the 44% figure is encouraging. Further research using a larger sample and refined measurement scales (based upon the present results) should provide a greater predictive capacity.

Multiple correlations were also computed for the Wyle and BOSDET groups. The results for the Wyle group were comparable to those for the public sample. Appearance alone accounted for 24% of the variance in wearability/accessibility ($r^2 = 0.24$). The best predicter for the Wyle sample was the combination of appearance and image. Together, these dimensions accounted for 34% of the variance in wearability/accessibility ($R^2 = 0.34$).

For the BOSDET group, the best predictor of wearability/accessibility was comfort. This variable accounted for 44% of the variance ($r^2 = 0.44$). The addition of other variables did not result in a significant increase in predictive power over comfort alone.

In summary, the present results suggest the following conclusions:

- The results obtained from the Wyle group are reasonably similar to those of the public group.
- The results obtained from the BOSDET group are dissimilar from those of the public group in a number of important respects.
- The principal difference between the Wyle and public groups was in the relationship of perceived effectiveness/reliability to comfort and image.
- Wearing the PFDs for several hours as opposed to simply trying them on had no reliable effect on subjects' ratings of PFDs on any of the dimensions used in this study.
- The belt type PFD (Davy Belt) which was expected to be more wearable, was not rated significantly superior to the Type III devices used in this study on any of the dimensions.
- The Davy Belt was perceived as being less effective and reliable than any of the other devices used in this study.
- Of the dimensions measured in the present study, that which best predicted wearability/accessibility for the public group was PFD appearance. Appearance accounted for 27% of the variance in wearability/accessibility, while the next best predictor accounted for less than 8% of the variance.
- The best available predictor of wearability/accessibility was the combination of the PFD appearance and image dimensions. Together these variables accounted for 44% of the variance.

A major surprise of the present study was the failure of the Davy Belt device to show higher wearability ratings than the Type III devices. The poor showing of the Davy Belt cannot be attributed to its low perceived effectiveness/reliability because this dimension was only weakly correlated with wearability/accessibility ($r = 0.20$). Three hypotheses concerning poor showing of the Davy Belt will be suggested:

1) The fact that the device was unfamiliar to the participants affected its reported wearability.

2) Further improvements in PFD design beyond that afforded by the Type III devices will not by themselves have any great influence on PFD wearability. It is possible that the problem lies not with the PFD but with the boater. Perhaps the answer is to change the boaters' behavior and/or attitudes rather than the PFD.

3) Boaters would actually wear belt-type PFDs more than Type III devices but the reported wearability ratings do not accurately reflect this change in actual wearability.

Any combination of these hypotheses may be true. Future research should circumvent these possible problem areas by giving boaters the Davy Belt to wear for longer periods of time, by focusing more on changing boaters' behavior related to PFDs, and measure actual wear rates rather than reported wearability.

5.5 CONCLUSION

The results of the foregoing studies can be used to generate a preliminary PFD wearability index. In the present project, the wearability of a PFD is defined as the "probability that a boater will be wearing that type of PFD immediately prior to entering the water in an accident, assuming that the PFD is available to the boater." As discussed eariler, wearability defined in this way depends not only upon the design features of the PFD but also upon the boater's attitudes and motivation, and the boating environment. This fact may create a problem. If the influence of a boater's attitudes and motivation, and the environment is large relative to that of PFD design features, then a wearability index based on PFD properties alone will not accurately reflect the extent to which PFDs will be worn or used. The results of wearability study II (see Section 5.4.2.2 suggest that such a problem exists. The ideal solution would be to develop a wearability index which reflects boaters' attitudes, motivation, and the environment as well as PFD design features. However, such an index would not be very practical. In order to insure a high wear rate of PFDs, the Coast Guard would have to influence boaters' attitudes and motivation and the environment as well as PFD design. A more practical approach would be to change boaters' attitudes and motivation through educational programs. Education does not eliminate the need for a wearability index, however, since it can be only partially effective in altering boaters' attitudes and motivation.

The problem is the following. Assuming that the wearability index will be applied to control the availability of PFDs only and not the activity of boaters, how can it insure a high rate of wear? The education of boaters is one answer. Another answer may be to build motivators and attitude-change considerations into PFDs. This might be accomplished by the development of special purpose devices designed specifically to help the boater in his activity, say, fishing or water skiing, or to enhance the boater's image, as well as to keep him afloat. For example, PFDs for fishing could be designed to allow freedom of movement, have pockets to hold fishing equipment, and perhaps carry the emblem of boaters' organizations, such as Bass Anglers Sportsmen's Society. PFDs designed for water skiing could provide warmth or keep the wearer cool as conditions in a particular location demand, provide protection from impact with the water, and complement the wearer's skis and boat in pattern and color.

As yet only limited data has been obtained on the effect of factors such as image enhancement, complementing colors and patterns, and special-purpose features. The preliminary data, however, suggest that such factors are important. The two dimensions which best predicted PFD wearability in Study II (Section 5.4.2) were PFD appearance and image.

A preliminary wearability index has been formulated utilizing multiple regression methods. The index is based upon the data obtained in Wearability Study II. The reported wearability of a PFD can be predicted as follows:

$$W'_R = \alpha + \beta_1 \cdot A + \beta_2 \cdot I$$

where:

W'_R = the predicted wearability rating for the PFD.

A = the rated appearance of the PFD.

I = the rating of the PFD on the image dimension (see Section 5.4.2 for definition and discussion).

α, β_1, β_2 are the intercept and regression coefficients which are determined empirically from the data of Study II. In this case:

α = -2.56

β_1 = 0.776

β_2 = 0.764

The data of wearability study II can be used to generate points in a three-dimensional space which represent corresponding values of PFD appearance, image, and rated wearability. Each point represents the values of these three variables produced by a particular subject using a particular PFD. The above equation for W'_R or the wearability index represents the best fitting line to these points. Rather than attempting a three-dimensional picture, it is more convenient to collapse PFD Appearance and Image into a single variable and use a two-dimensional representation. The best fitting line then becomes:

$$W'_R = \alpha + X$$

where

$$X = \beta \cdot A + \beta_2 \cdot I$$

The best fitting line and the corresponding data points are shown in Figure 5-5. Even though both independent variables (appearance and image) were very strongly related to rated wearability ($F = 8.15$, $p < 0.025$), there still may be considerable error in predicting rated wearability. The dotted lines in Figure 5-5 show the 90% confidence limits for predictions of rated wearability, W'_R, given values of appearance and image (A and I). These confidence limits were calculated assuming that rated wearability is normally distributed with equal variance at all values along the abscissa. At this point sufficient data is not available to evaluate this assumption, so the confidence limits should be regarded as only approximate. Further research will be required to improve the prediction of rated wearability.

An additional problem in the development of the wearability index is the correspondence between rated and actual wearability. The equation given above expresses the wearability index in terms of rated wearability. Further modification of the equation is required in order that the index of wearability reflect the probability that the PFD is worn. As yet, only very limited data is available on the relationship between reported wearability and actual wear rates. As a rough approximation, the relationship between reported and actual wearability can be expressed as a linear function.

$$W_A = A + B \cdot W_R$$

where

W_R = reported wearability

W_A = actual wear rate, i.e., the probability that a particular PFD will be worn given that it is available

A and B are empirically determined parameters.

Preliminary estimates of A and B were obtained by using data on actual and reported wearability for Type II and Type III devices reported in Sections 5.3 and 5.4. The values obtained were:

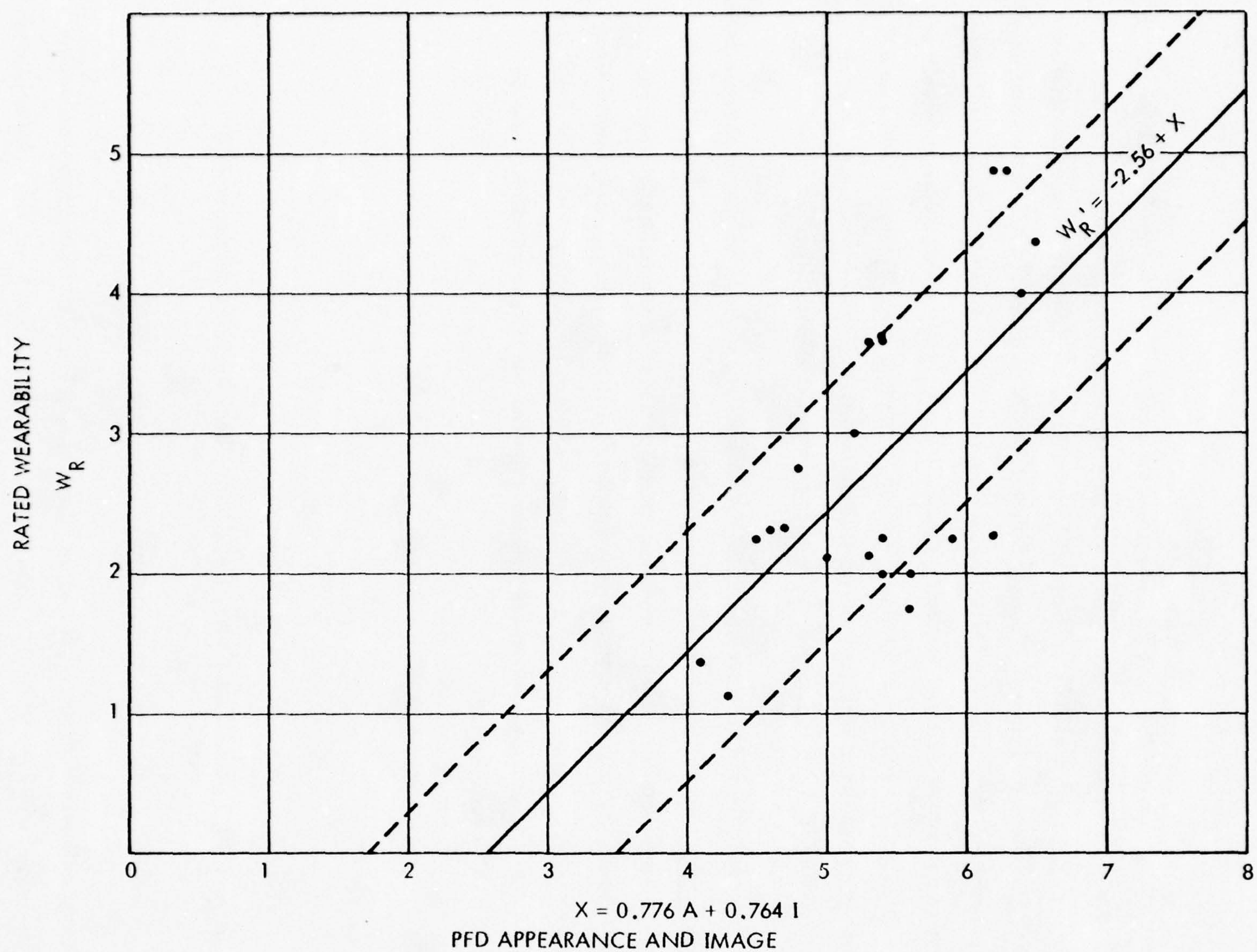

FIGURE 5-5. REPORTED WEARABILITY AS A FUNCTION OF PFD APPEARANCE AND IMAGE

$$A = 7.6$$

$$B = 12.6$$

Hence the relationship between reported and actual wearability can be expressed as:

$$W'_A = 7.6 + 12.6\, W_R$$

The preliminary wearability index expressed in terms of PFD appearance and image is then:

$$W'_A = -24.7 + 9.8A + 9.6\, I$$

This function is plotted in Figure 5-6. The above equation is presented only to demonstrate the form which the wearability index will take. It should not be interpreted at this point as a reliable estimate of wearability.

Research on wearability during Phase II of this project must address two objectives:

1) Improve the predictive capability of the Wearability Index by measuring actual wear rates in the boating environment, and by focusing more on PFD design factors related to the boater's motivation and enhancement of the boater's image.

2) Develop economical procedures for evaluating the wearability of PFDs submitted to the Coast Guard or its representative as a part of an approval process.

The development of the approval procedure for wearability depends on the accomplishment of the first objective. The first step is to develop regression equations which predict PFD wearability and accessibility within narrow limits. The development of such equations will be based on the PFD-related behavior of a large sample of boaters. Once the characteristics of the boating population relevant to PFD use are known, a smaller panel of boaters can be established to rate various characteristics of PFDs as part of an approval process. A panel would be chosen which generates ratings on the various dimensions related to wearability and accessibility which are representative of the boating population at large. The selection of the panel is a straight-forward application of survey-sampling methods like those employed by the large opinion polling organizations.

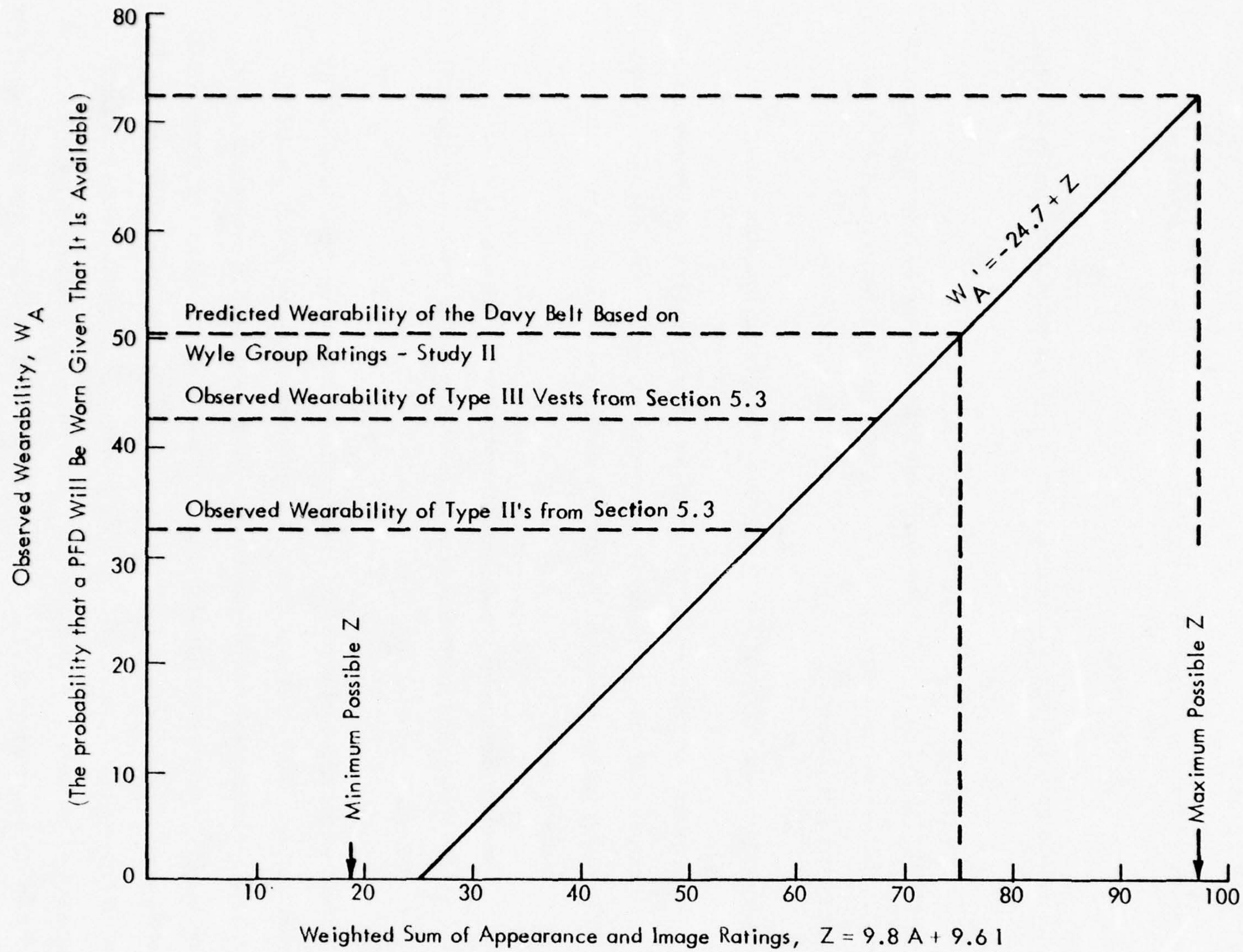

FIGURE 5-6. THE PRELIMINARY WEARABILITY INDEX

APPENDIX 5-A

INSTRUCTIONS AND CAUTIONARY MESSAGE
GIVEN TO PARTICIPANTS IN STUDY II

WYLE LABORATORIES

April 26, 1976

Dear Sir/Madam:

Thank you for volunteering to participate in our study of PFD (personal flotation device) "wearability" and comfort. Wyle Laboratories is a private company which performs a wide variety of research on boating safety for the United States Coast Guard.

Hundreds of boaters drown yearly for want of a PFD. The problem is that boaters generally have PFD's aboard, but do not wear them or keep them sufficiently accessible. Boating accidents often happen so quickly that the victims don't have time to get ahold of PFD's stored aboard the boat.

The purpose of this study is to assess the importance of a variety of factors which we believe may be related to PFD wear. We are also comparing PFD's to find out what features people like or dislike. This information will help the U.S. Coast Guard develop more flexible standards for PFD's. These new standards will allow manufacturers to come up with PFD's which are both more "wearable" and more successful in saving lives.

We are sending you two PFD's under separate cover. This is what we would like you to do:

a) When you receive the PFD's, try them on briefly and fill out one copy of the enclosed questionnaire. Please ask another person with whom you often go boating to do the same and fill out a separate questionnaire. We want to know your independent opinions, so please do not talk about or compare your answers.

b) On your next boat outing, wear each PFD for at least one hour, then fill out a new copy of the questionnaire. Please have the other person with whom you go boating do the same. Please do not look at the first questionnaire you filled out when completing the second. Your answers need not be the same on the first and second questionnaires.

EASTERN OPERATIONS
7300 Governors Drive West
Huntsville, Alabama 35807
837-4411 Area Code 205
TWX 810-726-2225

c) Return the questionnaires and PFD's as promptly as possible. Use the enclosed envelopes for the questionnaires. Ship the PFD's back parcel post using the same box in which they came and the enclosed address label. If you have not used the PFD's on a boat outing within two weeks after receiving them, please return them anyway so we can forward them to other participants. (If you live or work near Wyle, you may bring the questionnaires and PFD's to the Marine Technology Department.)

For your own safety, please do not use the PFD's in any activities of which you do not normally partake. Take all prudent and necessary precautions. PFD's are fallible.

I want to thank you for your participation. As a token of our appreciation, we would like you to have one of the PFD's which you have rated. The PFD will arrive after the conclusion of the study (about June 1st). Please indicate your preference below. We will also send you a check to cover the cost of returning the PFD's to us by parcel post.

Again, thank you. Please call me at the following toll-free number if you should have any questions or comments whatsoever - 800/633-2086.

Sincerely,

WYLE LABORATORIES

Theodore J. Doll, Ph.D.
Sr. Research Psychologist

PFD Preference

Style: Vest Yoke/Collar Belt (Circle one)

Color: ____________________ Manufacturer: ______________________________

APPENDIX 5-B

INFORMATIONAL AND CONSENT FORM DISTRIBUTED TO PARTICIPANTS USING THE DAVY BELT IN STUDY II

TO PARTICIPANTS IN THE PFD WEAR STUDY USING THE INFLATABLE DAVY BELT

You should be aware that the Davy Belt is not a Coast Guard approved PFD. This does not mean that the Davy Belt is unreliable, simply that it has not been thoroughly tested and evaluated. When you encounter conditions in which you would normally wear a PFD, please don your customary device over the Davy Belt. Also, please read the instructions enclosed with each Davy Belt. Be sure you know how to don it properly and how to actuate it. Please note that the Davy Belt does not actuate automatically when immersed, and that the CO_2 cartridge must be replaced before the device can be re-actuated. Once actuated, do not wear the Davy Belt again until a fresh CO_2 cartridge has been installed and the inflatable tube is properly re-packed.

If you have any questions about the Davy Belt, please call me at the following number before using it - 837-4411, Ext. 429.

Please sign in the space provided below after you are satisfied that you fully understand how to properly use the Davy Belt and are aware of its limitations. Return this form in the envelope provided (or bring this form to the Marine Technology Department) before using the Davy Belt.

WYLE LABORATORIES

Theodore J. Doll

Theodore J. Doll, Ph.D.
Sr. Research Psychologist

____

____

Signature of participants using the Davy Belt

APPENDIX 5-C. QUESTIONNAIRE FOR WEARABILITY STUDY II

PART 1

START HERE: Please fill out this form before using the two PFD's you have been given, then fill out a second copy of this form after wearing each PFD for at least 2 hours. When filling out this form the second time, do not refer to the copy completed earlier.

Name ______________________

This copy was filled out:

_____ Before wearing the PFD's (for more than a few minutes)

_____ After wearing the PFD's for at least 2 hours each

Address ______________ ______________
(Street and Number) (City, State, Zip Code)

You need fill in the remainder of Part 1 only after wearing the PFD's. If this is the "before-wear" rating, skip to Part 2

Age ________ Sex ________ (M/F)

Formal Instruction in Boating Safety (check only those you have completed)

_____ USCG Auxiliary _____ American Red Cross _____ None

_____ U.S. Power Squadron _____ State _____ Other - Specify: ________

Hours of Boating Experience:

_____ Under 20 hours _____ 100-500 hours

_____ 20-100 hours _____ Over 500 hours

Phone: Business ____________ Home ____________ Date of Outing ______________
Mo/Day/Year

Time departed ____________ a.m./p.m. Returned ____________ a.m./p.m. Number of People on board ________

Weather: Rain _____ Sunny _____ Cloudy _____ Fog/Haze _____ Approximate Air Temperature _____ °F Wind: Calm _____ Moderate _____ Strong _____

Water Conditions: Calm _____ Choppy _____ Rough _____ Swift Current _____

Location of Principal Boating Activity: River _____ Lake _____ Ocean _____ Bay, Sound, Inlet or Harbor _____

Manufacturer and Model of Boat ______________ Power ______ (HP) Length Overall ______ ft.

Activities of person rating the PFD's: Waterskiing _____ Fishing _____ Pleasure Cruising _____ Sailing _____ Diving _____ Swimming _____ Hunting _____ Operating Boat _____ Other (please specify) ______________

PART 2

INSTRUCTIONS TO THE PARTICIPANT:

Please rate the two PFD's you have used or will use today on each of the scales shown at the right. Carefully read the questions and circle one of the numbers shown to indicate your extent of agreement with the statement for each PFD. Use only the numbers shown.

Please describe the two PFD's you are rating below:

	Wyle # ______ Color ______ Style: Vest, Yoke/Collar, Belt (circle one) Manufacturer ______ # Hours Worn ______					Wyle # ______ Color ______ Style: Vest, Yoke/Collar, Belt (circle one) Manufacturer ______ # Hours Worn ______				
1. Before beginning this scale, adjust the PFD to your size, if possible. Do not consider any difficulty in adjusting the PFD to size in this rating. Now don and fully fasten the PFD. Rate the PFD on how easy it is to don and fasten by considering the following statement:	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
This PFD is easy to don and fasten......	1	2	3	4	5	1	2	3	4	5
2. The color and/or pattern of the covering on this PFD is very attractive........... (Rate preferred side if reversible)	1	2	3	4	5	1	2	3	4	5
3. The shape of this PFD is odd and would look strange on a person......	1	2	3	4	5	1	2	3	4	5
4. This PFD does not rub, scrape, or pinch the wearer's skin.......	1	2	3	4	5	1	2	3	4	5
5. This PFD does not detract from the appearance of the person who wears it.....	1	2	3	4	5	1	2	3	4	5
6. This PFD would help keep the wearer warm in cool weather......	1	2	3	4	5	1	2	3	4	5
7. This PFD is not excessively hot or sweaty in warm weather.....	1	2	3	4	5	1	2	3	4	5
8. This PFD feels bulky and uncomfortable when worn.......	1	2	3	4	5	1	2	3	4	5
9. This PFD does not restrict my movement or get in my way during boating activities...	1	2	3	4	5	1	2	3	4	5
10. This PFD fits snugly all around, but not too tightly.......	1	2	3	4	5	1	2	3	4	5
11. This PFD tends to ride up or otherwise be uncomfortable when the wearer is in a sitting or reclining position......	1	2	3	4	5	1	2	3	4	5

Please continue on the reverse side

Please copy this information exactly as shown on the reverse side →	Wyle # ______ Color ______ Style: Vest, Yoke/Collar, Belt (circle one)					Wyle # ______ Color ______ Style: Vest, Yoke/Collar, Belt (circle one)				
	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
12. The pockets (if any) on this PFD are useful and convenient........	1	2	3	4	5	1	2	3	4	5
13. This PFD looks like it would be highly effective under normal conditions in keeping the wearer's head out of the water so that he could breathe.......	1	2	3	4	5	1	2	3	4	5
14. This PFD looks like it would work well even in very rough water......	1	2	3	4	5	1	2	3	4	5
15. In a harsh boating environment, this PFD might deteriorate quickly to the point where it would malfunction.......	1	2	3	4	5	1	2	3	4	5
16. In a boating emergency I'd probably be better off without any PFD than with this PFD.........	1	2	3	4	5	1	2	3	4	5
17. This PFD is probably relatively inexpensive compared to other PFD's.......	1	2	3	4	5	1	2	3	4	5
18. If I had a PFD of this type available, I would wear it most or all of the time while boating.	1	2	3	4	5	1	2	3	4	5
19. I would probably wear this PFD only in very rough conditions......	1	2	3	4	5	1	2	3	4	5
20. This PFD would be reasonably comfortable to wear for hours at a time......	1	2	3	4	5	1	2	3	4	5
21. If this were the only type of PFD aboard my boat, I would insist that non-swimmers and young children wear one.....	1	2	3	4	5	1	2	3	4	5
22. If this were the only type of PFD aboard my boat, I would insist that all my passengers wear one......	1	2	3	4	5	1	2	3	4	5
23. The experienced boater would probably not wear this PFD under normal conditions.....	1	2	3	4	5	1	2	3	4	5
24. If I had only this type of PFD aboard my boat I would keep several out in the open so they would be accessible in case of an emergency.	1	2	3	4	5	1	2	3	4	5
25. If I kept PFD's of this type lying out in the open aboard my boat, experienced boaters or friends would probably think I was being over-cautious........	1	2	3	4	5	1	2	3	4	5
26. If inexperienced passengers saw PFD's of this type lying around a boat, they might think the operator was expecting trouble..	1	2	3	4	5	1	2	3	4	5
27. If inexperienced passengers saw PFD's of this type lying around a boat, they would probably feel safer.....	1	2	3	4	5	1	2	3	4	5
28. This PFD looks awkward and unattractive on most people......	1	2	3	4	5	1	2	3	4	5
29. Wearing this PFD would seriously interfere with my normal activities while boating...	1	2	3	4	5	1	2	3	4	5
30. This PFD provides about the right amount of body coverage for my boating activities....	1	2	3	4	5	1	2	3	4	5
31. This PFD probably costs over $20 (retail)...	1	2	3	4	5	1	2	3	4	5
32. This PFD can be conveniently used as a cushion to sit or recline on.........	1	2	3	4	5	1	2	3	4	5

Thank you. Please return these forms to Wyle Laboratories in the envelopes provided.

6.0 PFD RELIABILITY

6.1 INTRODUCTION

At the inception of this project the reliability of Coast Guard approved PFDs was generally believed to be quite high. However, recent tests by Wyle, later confirmed by Underwriters' Laboratories, showed a very high rate of failure, even among new PFDs. Thus reliability may be a serious problem affecting the overall life-saving capability of PFDs.

The research conducted to date has considered only inherently buoyant devices and has been exploratory in nature. Major reliability problem areas have been identified and methods for the evaluation of PFD reliability have been outlined.

One purpose of the reliability research is to develop methods for determining whether a PFD will perform up to its design potential or USCG standards. Causes for PFD failure and possible countermeasures are also of interest. In addition to determining PFD reliability, there exists the need to determine the expected useful life of PFDs. Up to now, the Coast Guard and state Marine Officers have had to judge PFD reliability solely on visual inspection for such things as torn seams, broken fasteners, etc. Thus, a second purpose of this work on PFD reliability is to establish a method for estimating the useful life of PFDs currently in use and of any newly designed PFDs.

Besides the evaluation and improvement of PFDs that are currently approved by the Coast Guard, a methodology is required to evaluate the reliability aspects of inflatable and hybrid devices. This methodology would include some differences due to the fact that inflatable and hybrids pose new issues of reliability such as cell puncture, leakage, gas actuator failure and human factors problems associated with manually operated devices. These problems are under study by Wyle and are discussed under the alternate concepts section.

6.2 APPROACHES TO DETERMINING RELIABILITY

Two basic approaches exist for determining a PFD's reliability. One method is to determine the reliability as a function of the failure probability of each of the individual components of the PFD, and from there derive the reliability of the PFD as a system. The other approach is to study the failure characteristics of the PFDs as units and then derive a failure rate and subsequent reliability of PFDs.

One version of the first approach is described in a report prepared for the Coast Guard by Operations Research, Inc.[1] Under this method, the reliabilities of each of the components, also known as Engineering Reliability Units (ERUs), and the type of interdependencies between components are combined mathematically to compute the reliability for the whole PFD. This approach would permit the calculation of: 1) overall PFD reliability, 2) given that a defect exists in a PFD component, the probability that it is not detected, and 3) the probability that the same defect is detected.

The main criticisms of this method lie with its complexity. If this approach were used, the method for combining reliability of components should be kept as simple as possible in order to make interpretation of results meaningful. A second criticism is that each ERU would have to be aged and tested leading to a large number of tests. The third and most important criticism of the ERU approach is that unless the PFD standard specified the exact components (i.e., materials, buckles, fasteners, etc.) to be used and how they are to function in relation to the whole PFD, the ERU approach would be impossible to use. The ERU approach would lead to the establishment of construction standards. Recent Coast Guard policy has been to move toward performance standards.

The second approach, which was adopted by Wyle in its approach to PFD reliability, involved the testing of the PFD as a whole unit for reliability.

6.2.1 Reliability Test Program

In testing for reliability, methods need to be devised that will test for all possible failure modes. Underwriters' Laboratories has devised methods for testing of life saving devices. (UL 1123 - ANSI Z243.1-1972 Water Safety Buoyant Devices) Wyle has adopted and modified

[1] Greenhouse, L., Kerne, B. and Weiers, D., A Reliability Investigation of Personal Flotation Devices, Phase I, Operations Research, Inc., CG-D-13-74, 1973. NTIS No. AD 770 210

some of these procedures in devising their own Reliability Testing Program (see Appendices 6-A through 6-E).

6.2.2 Problem Definition

The first step in devising such a program is to define what we mean by reliability, or more exactly, what constitutes a failure. The classical definition of reliability is generally expressed as follows:

> Reliability is the probability that a device will operate successfully for a specified period of time and under specified conditions, when used in the manner and for the purpose intended.

This definition has many implications. The first one is that when we say "reliability is a probability" we mean that reliability is a variable. The next implication concerns the statement "will operate successfully." Here we need to define more clearly what is the intended operation of the PFD. For purposes of our study we will define successful operation as "the capability of the PFD to be donned and fastened easily by the person and to provide the required 15.5 lb of buoyancy." An example of a successful operation of a PFD would be where upon entering the water the PFD provides the needed buoyancy and support without a need for the person to hold onto it due to broken fasteners.

6.2.3 Reliability Tests

The most obvious failure mode to consider is that of failure of the PFD to provide the needed buoyancy for the time period it is needed. Current test standards (UL 1123) specify that PFDs shall provide at least 15.5 lb of buoyancy for a period of 24 hours for fibrous materials and for 48 hours for non-fibrous materials. Current research by Wyle has led us to believe that a long test period is not needed. Results from ARM_4 (Accident Recovery Model-4) show that in accidents involving people having to enter the water, 84% are recovered within the first half hour and 88% are recovered within the first two hours. Therefore, a more realistic requirement might be that the PFD provide at least 15.5 lb of buoyancy for a period of four hours. Information of this type is needed in order to determine what sort of standards for PFD reliability will best reflect the needs of recreational boaters.

Besides buoyancy, methods are needed to test for damage due to sudden impacts such as a skier falling or a person falling from a fast moving boat, and to test for the effects from extensive pulling due to donning it. The tests to be used include an impact test whereby the PFD is exposed to a water impact of 35 mph in various positions (Appendix 6-D) and a tensile test whereby the PFD is put under a high level of stress to test for weak or broken fasteners or straps (Appendix 6-D).

The probability that a PFD will pass all three tests, or the reliability of a given type of PFD at a specified age can be expressed as:

$$R_{PFD} = P_B \cdot P_T \cdot P_I$$

where

R_{PFD} = the reliability of the PFD

P_B = the probability of a PFD successfully passing the buoyancy test

P_T = the probability of a PFD successfully passing the tensile test

P_I = the probability of a PFD successfully passing the impact test.

6.2.4 Accelerated Aging and Stressing Procedures

The purpose of accelerated testing is to gather as much failure data as possible in a short time frame. Through accelerated testing, the "real world effects" are simulated by putting the PFDs under environmental conditions that are far more severe than those normally encountered in real-life. This causes the PFDs to fail more quickly and thus drastically reduce both the time and number of PFDs needed.

The real-life stressors that cause various failure modes in PFDs can be classified as environmental stressors such as sunlight and humidity and general usage stressors such as impact upon hitting the water (i.e., in water skiing), general abuse, or lack of adequate maintenance.

The modeling of general usage stressors will be accomplished by use of an impact procedure to simulate a skier or swimmer hitting the water; the roller procedure to simulate trampling, sitting and general abuse; the fastener exercise procedure to simulate fastening and unfastening the PFD; and the tensile procedure to simulate donning, pulling and stretching of the PFD (Appendix 6-E).

Environmental stressors that need to be modeled would include sunlight, humidity, temperature, and water exposure. A possible method for accomplishing this would include cycling the PFD through water immersion, sunlight exposure and high temperatures during the day and exposing the PFD to cold temperatures at night using the stress testing methods available at Wyle. This would be correlated to the different exposures at sites throughout the country for sunlight, water immersion, and temperature cycle and thus modeling the stress level for different parts of the country.

Methods for correlating these accelerated aging and stressing procedures to "real world aging" are discussed in the Conclusions and Recommendations section.

6.3 RESULTS

Initially, a total of 118 new and used PFDs were collected for initial testing and for validation of buoyancy test procedures. This sample consisted of PFDs collected from a variety of manufacturers with 77 Type III, 30 Type II, nine Type IV, and one Type V tested. These PFDs were subjected to either an "all-or-none" buoyancy test and/or an incremental buoyancy test to establish whether the PFDs satisfied the Coast Guard buoyancy requirement. As a secondary task, the PFDs were visually examined for defects, such as broken zippers and torn seams, that would impair their normal operation. Next, a small selection of PFDs that passed previous testing were put through a 24 hour submersion test and then retested for buoyancy.

Overall, for both new and used PFDs combined, there were 19 out of 94 adult-size PFDs failing to meet initial buoyancy requirements with 18 of these failures being Type III and one of the failures being a Type II. No failures were noted among child-size PFDs or Type IVs. Based on this sample, it appears that our most serious problem with reliability lies with Type IIIs. These findings are even more surprising if the results from submersion testing are included. Out of 14 Type III PFDs that passed initial buoyancy tests and then were put through 24 hour submersion tests, three more failed to pass minimum buoyancy requirements.

6.3.1 Used PFD Results

An analysis of used PFDs vs. new PFDs reveals several interesting factors. Initially, a total of 34 used PFDs were tested for minimum buoyancy requirements. Results show that nearly 21% of all used PFDs collected (up to six years of age) failed (Table 6-1). But when it is noted that all of these failures were Type III, this failure percentage rises to 33% for used Type III devices.

An analysis of these results on used PFDs suggest possible areas in which to look for causes. For instance, five out of seven PFDs which failed the buoyancy test were made by the same manufacturer and were composed of the same flotation material. This suggests that the problem with these used PFDs lies either with manufacturing problems in design and quality control or the buoyant material.

Test Unit No.	Style	Manufactured By	Type	Size	Flotation Material
1	Vest	Gaylord Horr	III	XXL	C.C. PVC F.
2	Vest	America's Cup	III	S	Foam
3	Jacket	Stearns	III	M	C.C. PVC F.
4	Vest	Stearns	III	M	C.C. PVC F.
5	Vest	Omega Market	III	M	Foam
6	Vest	Stearns	III	M	C.C. PVC F.
7	Yoke	Buddy Schoellkopf	II	Adult	Kapok in plastic bags
8	Vest	America's Cup	III	S	Foam
9	Vest	Gentex	III	M	Unicellular plastic foam
10	Vest	Stearns	III	L	C.C. PVC F.
11	Vest	Gentex	III	M	Unicellular plastic foam
12	Vest	Stearns	III	L	C.C. PVC F.
13	Yoke	Gladding	II	> 90 lb	Kapok in plastic bags
14	Yoke	Crawford	II	> 90 lb	Kapok in plastic bags
15	Yoke	Gladding	II	Adult	Kapok in plastic bags
16	Vest	Gentex	V	M	Unicellular plastic foam
17	Vest	Stearns	III	L	C.C. PVC F.
18	Vest	Stearns	III	XL	C.C. PVC F.
19	Vest	Stearns	III	L	C.C. PVC F.
20	Vest	Stearns	III	L	C.C. PVC F.
21	Yoke	Gladding	II	Adult	Kapok in plastic bags
22	Vest	Superior	III	Adult	Ensolite vinyl foam
23	Yoke	Gladding	II	Adult	Kapok in plastic bags
24	Vest	Stearns	III	L	C.C. PVC F.
25	Yoke	Gladding	II	Adult	Kapok in plastic bags
26	Vest	Stearns	III	L	C.C. PVC F.
27	Vest	Stearns	III	L	C.C. PVC F.
28	Vest	Gentex	III	M	Unicellular plastic foam
29	Yoke	Kent Sporting Goods	II	> 90 lb	Kapok in plastic bags
30	Vest	Stearns	III	L	C.C. PVC F.
31	Belt	SOS Swimware	-	Adult	CO_2 in plastic
32	Throwable	Atlantic and Pacific	IV	N/A	Firm plastic foam
33	Throwable	Safeguard	IV	N/A	Kapok in plastic bag
34	Throwable	Safeguard	IV	N/A	Kapok in plastic bag
35	Yoke	Kent Sporting Goods	II	> 90 lb	Kapok in plastic bag
36	Vest	Stearns	III	M	C.C. PVC F.
37	Vest	Stearns	III	L	C.C. PVC F.
38	Yoke	Safeguard	II	Adult	Kapok in plastic bag
39	Throwable	Cal June	IV	N/A	Closed cell polystyrene core
40-49	(Unused Nos.)				

TABLE 6-1. PFD TEST RESULTS

Flotation Material	Age	Hardware Flaws	Effective Buoyancy Test	Incremental Buoyancy Reading	After Submersion Testing (a)	(b)
C. PVC F.	2	-	Failed	13 lb 9 oz	-	-
am	2	-	Passed	-	-	-
C. PVC F.	2	-	Failed	15 lb 7 oz	-	-
C. PVC F.	2	-	Passed	16 lb 10 oz	-	-
am	1	-	Passed	16 lb 8 oz	-	-
C. PVC F.	2	Zipper broke	Passed	16 lb 4 oz	-	-
pok in plastic bags	1	-	Passed	19 lb 0 oz	-	-
am	1	-	Passed	17 lb 0 oz	-	-
icellular plastic foam	2	-	Passed	17 lb 10 oz	-	-
C. PVC F.	1	Zipper broke	Passed	17 lb 12 oz	-	-
icellular plastic foam	New	-	Passed	-	-	-
C. PVC F.	2	-	Passed	17 lb 8 oz	-	-
pok in plastic bags	1	-	Passed	19 lb 15 oz	-	-
pok in plastic bags	2	-	Passed	-	-	-
pok in plastic bags	4	-	Passed	-	-	-
icellular plastic foam	1	Zipper pull missing	Passed	-	-	-
C. PVC F.	2	Zipper hard to start	Passed	16 lb 8 oz	-	-
C. PVC F.	1	-	Failed	14 lb 15 oz	-	-
C. PVC F.	1	-	Failed	15 lb 7 oz	-	-
C. PVC F.	1	Zipper missing	Passed	15 lb 15 oz	-	-
pok in plastic bags	4	Belt edges cut and frayed	Passed	-	-	-
solite vinyl foam	3	-	Failed	12 lb 10 oz	-	-
pok in plastic bags	4	Hook missing	Passed	-	-	-
C. PVC F.	1	Zipper teeth missing	Failed	15 lb 7 oz	-	-
pok in plastic bags	6	Belt edges cut and frayed	Passed	17 lb 4 oz	-	-
C. PVC F.	1	Zipper pulled out	Failed	15 lb 4 oz	-	-
C. PVC F.	2	-	Passed	15 lb 8 oz	-	-
icellular plastic foam	New	-	Passed	15 lb 9 oz	-	-
pok in plastic bags	1/2	-	Passed	17 lb 12 oz	-	-
C. PVC F.	1	Zipper pulled out	Passed	18 lb 8 oz	-	-
O_2 in plastic	1	-	Passed	17 lb 10 oz	-	-
m plastic foam	3	-	-	16 lb 12 oz	-	-
pok in plastic bag	New	-	-	21 lb 14 oz	-	-
pok in plastic bag	New	-	-	19 lb 13 oz	-	-
pok in plastic bag	New	-	Passed	-	-	-
C. PVC F.	2	-	Passed	16 lb 8 oz	-	-
C. PVC F.	1	-	Passed	17 lb 14 oz	-	-
pok in plastic bag	2	-	Passed	17 lb 12 oz	-	-
osed cell polystyrene core	1-1/2	-	-	17 lb 7 oz	-	-

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50	Yoke	Safeguard	II	Adult	Kapok in plastic bag	N
51	Yoke	Safeguard	II	Adult	Kapok in plastic bag	N
52	Yoke	Safeguard	II	Adult	Kapok in plastic bag	N
53	Yoke	Safeguard	II	> 50 - < 90 lb	Kapok in plastic bag	N
54	Yoke	Safeguard	II	> 50 - < 90 lb	Kapok in plastic bag	N
55	Yoke	Safeguard	II	> 50 - < 90 lb	Kapok in plastic bag	N
56	Yoke	Safeguard	II	< 50 lb	Kapok in plastic bag	N
57	Yoke	Safeguard	II	< 50 lb	Kapok in plastic bag	N
58	Cushion	Safeguard	IV	15" x 15" x 2-1/2"	Kapok in plastic bag	N
59	Cushion	Safeguard	IV	15" x 15" x 2-1/2"	Kapok in plastic bag	N
60	Vest	Stearns	III	S (36-38)	C.C. PVC F.	N
61	Vest	Stearns	III	S (36-38)	C.C. PVC F.	N
62	Vest	Stearns	III	Petite (32-34)	C.C. PVC F.	N
63	Vest	Stearns	III	Petite (32-34)	C.C. PVC F.	N
64	Vest	Stearns	III	S	C.C. PVC F.	N
65	Vest	Stearns	III	S	C.C. PVC F.	N
66	Vest	Stearns	III	M	C.C. PVC F.	N
67	Vest	Stearns	III	M	C.C. PVC F.	N
68	Vest	Stearns	III	L	C.C. PVC F.	N
69	Vest	Stearns	III	L	C.C. PVC F.	N
70	Vest	America's Cup	III	XL	C.C. PVC F.	N
71	Vest	Stearns	III	L	C.C. PVC F.	N
72	Vest	Stearns	III	M	C.C. PVC F.	N
73	Vest	Stearns	III	M	C.C. PVC F.	N
74	Vest	Stearns	III	L	C.C. PVC F.	N
75	Vest	Stearns	III	M	C.C. PVC F.	N
76	Vest	Stearns	III	M	C.C. PVC F.	N
77	Vest	Stearns	III	M	C.C. PVC F.	N
78	Vest	Stearns	III	M	C.C. PVC F.	N
79	Vest	Stearns	III	M	C.C. PVC F.	N
80	Vest	America's Cup	III	XL	Foam	N
81	Vest	America's Cup	III	M	Foam	N
82	Vest	America's Cup	III	M	Foam	N
83	Vest	America's Cup	III	M	Foam	N
84	Vest	America's Cup	III	M	Foam	N
85	Vest	America's Cup	III	XL	Foam	N
86	Vest	Stearns	III	L	C.C. PVC F.	N
87	Vest	Stearns	III	L	C.C. PVC F.	N
88	Yoke	Red Head	II	> 50 - < 90 lb	Kapok in plastic covers	N
89	Yoke	Red Head	II	> 50 - < 90 lb	Kapok in plastic covers	N
90	Yoke	Red Head	II	> 50 - < 90 lb	Kapok in plastic covers	N

TABLE 6-1. PFD TEST RESULTS (continued)

Material	Age	Hardware Flaws	Effective Buoyancy Test	Incremental Buoyancy Reading	After Submersion Testing (a)	(b)
stic bag	New	-	Passed	-	-	-
stic bag	New	Bag leaked	Passed	-	-	-
stic bag	New	-	Passed	-	-	-
stic bag	New	Bag ripped	-	12 lb 4 oz	-	-
stic bag	New	Bag ripped	-	12 lb 8 oz	-	-
stic bag	New	-	-	12 lb 4 oz	-	-
astic bag	New	-	-	7 lb 8 oz	-	-
astic bag	New	-	-	7 lb 12 oz	-	-
astic bag	New	-	-	20 lb 1 oz	-	-
astic bag	New	-	-	19 lb 14 oz	-	-
F.	New	-	Passed	16 lb 5 oz	Yes	N/T
F.	New	Zipper sticks	Passed	-	-	-
F.	New	-	Passed	16 lb 6 oz	Yes	15 lb 14 oz
F.	New	-	Passed	-	-	-
F.	New	-	Failed	15 lb 0 oz	-	-
F.	New	-	Passed	15 lb 10 oz	-	-
F.	New	-	Passed	-	No	N/T
F.	New	-	Passed	16 lb 3 oz	No	15 lb 7 oz
F.	New	-	Passed	-	Yes	N/T
F.	New	-	Passed	-	-	-
F.	New	-	Failed	14 lb 6 oz	-	-
F.	New	-	Passed	-	-	-
F.	New	-	Passed	-	-	-
F.	New	-	Passed	-	-	-
F.	New	-	Passed	-	Yes	16 lb 4 oz
F.	New	-	Passed	-	-	-
F.	New	-	Passed	-	No	N/T
F.	New	-	Passed	-	Yes	15 lb 8 oz
F.	New	-	Passed	16 lb 2 oz	-	-
F.	New	-	Passed	16 lb 0 oz	-	-
	New	-	Failed	14 lb 5 oz	-	-
	New	-	Passed	15 lb 14 oz	-	-
	New	-	Passed	-	-	-
	New	-	Passed	15 lb 15 oz	Yes	N/T
	New	-	Passed	-	Yes	15 lb 11 oz
	New	-	Failed	14 lb 7 oz	-	-
F.	New	-	Passed	16 lb 0 oz	-	-
F.	New	-	Passed	16 lb 6 oz	-	-
astic covers	New	-	-	12 lb 4 oz	-	-
astic covers	New	-	-	11 lb 4 oz	-	-
astic covers	New	-	-	11 lb 8 oz	-	-

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Test Unit No.	Style	Manufactured By	Type	Size	Flotation Material	A
91	Yoke	Red Head	II	> 50 - < 90 lb	Kapok in plastic covers	Ne
92	Vest	Cypress Gardens	III	L	Unicellular plastic foam	Ne
93	Vest	Cypress Gardens	III	L	Unicellular plastic foam	Ne
94	Vest	Cypress Gardens	III	L	Unicellular plastic foam	Ne
95	Vest	Cypress Gardens	III	L	Unicellular plastic foam	Nei
96	Vest	Cypress Gardens	III	M	Unicellular plastic foam	Ne
97	Vest	Cypress Gardens	III	L	Unicellular plastic foam	Ne
98	Vest	Cypress Gardens	III	L	Unicellular plastic foam	Ne
99	Vest	Cypress Gardens	III	M	Unicellular plastic foam	Ne
100	Vest	Cypress Gardens	III	L	C.C. PVC F.	Ne
101	Vest	Cypress Gardens	III	L	C.C. PVC F.	Ne
102	Vest	Cypress Gardens	III	L	C.C. PVC F.	Ne
103	Vest	Cypress Gardens	III	L	C.C. PVC F.	Ne
104	Vest	Cypress Gardens	III	L	C.C. PVC F.	Ne
105	Vest	Cypress Gardens	III	L	C.C. PVC F.	Ne
106	Vest	Cypress Gardens	III	M	C.C. PVC F.	Ne
107	Vest	Cypress Gardens	III	M	C.C. PVC F.	Ne
108	Vest	America's Cup	III	L - XL	Foam	Ne
109	Vest	America's Cup	III	L	Foam	Ne
110	Vest	America's Cup	III	L	Foam	Ne
111	Vest	America's Cup	III	L	Foam	Ne
112	Vest	America's Cup	III	L	Foam	Ne
113	Vest	America's Cup	III	L	Foam	Ne
114	Vest	America's Cup	III	L	Foam	Ne
115	Yoke	Style Crafters	II	Adult	Unicellular plastic foam	N
116	Yoke	Style Crafters	II	Adult	Unicellular plastic foam	N
117	Yoke	Gladding	II	50 - 90 lb	Unicellular polystyrene foam	N
118	Yoke	Gladding	II	50 - 90 lb	Unicellular polystyrene foam	N
119	Yoke	Gladding	II	50 - 90 lb	Unicellular polystyrene foam	N
120	Yoke	Gladding	II	50 - 90 lb	Unicellular polystyrene foam	N
121	Yoke	Gladding	II	< 50 lb	Unicellular polystyrene foam	N
122	Yoke	Gladding	II	< 50 lb	Unicellular polystyrene foam	N
123	Cushion	Farbar Brothers	IV	14" x 17" x 2"	Kapok in plastic bag	N
124	Cushion	Farbar Brothers	IV	14" x 17" x 2"	Kapok in plastic bag	N
125	Cushion	Farbar Brothers	IV	14" x 17" x 2"	Kapok in plastic bag	N
126	Vest	Stearns	III	L	C.C. PVC F.	N
127	Vest	Stearns	III	M	C.C. PVC F.	N
128	Vest	Stearns	III	M	C.C. PVC F.	N

(a) Supports 15.5 lb

(b) Incremental Buoyancy reading

TABLE 6-1. PFD TEST RESULTS (concluded)

Material	Age	Hardware Flaws	Effective Buoyancy Test	Incremental Buoyancy Reading	After Submersion Testing (a)	After Submersion Testing (b)
tic covers	New	Slow leak	-	11 lb 10 oz	-	-
lastic foam	New	-	Passed	-	-	-
lastic foam	New	-	Passed	-	-	-
lastic foam	New	-	Passed	17 lb 2 oz	Yes	N/T
lastic foam	New	-	Passed	-	Yes	17 lb 9 oz
lastic foam	New	-	Passed	-	-	-
lastic foam	New	-	Passed	-	-	-
lastic foam	New	-	Passed	18 lb 4 oz	-	-
lastic foam	New	-	Passed	-	-	-
.	New	-	Passed	-	Yes	N/T
.	New	-	Passed	-	-	-
.	New	-	Passed	16 lb 10 oz	Yes	16 lb 2 oz
.	New	-	Passed	16 lb 6 oz	-	-
.	New	-	Passed	-	-	-
.	New	-	Passed	-	-	-
.	New	-	Passed	-	-	-
.	New	-	Passed	16 lb 4 oz	-	-
	New	-	Failed	14 lb 3 oz	-	-
	New	-	Failed	13 lb 2 oz	-	-
	New	-	Failed	12 lb 5 oz	-	-
	New	-	Failed	13 lb 0 oz	-	-
	New	-	Failed	13 lb 5 oz	-	-
	New	-	Failed	13 lb 7 oz	-	-
	New	-	Failed	13 lb 5 oz	-	-
plastic foam	New	-	Passed	15 lb 12 oz	-	-
plastic foam	New	-	Failed	15 lb 7 oz	-	-
polystyrene foam	New	-	-	11 lb 10 oz	-	-
polystyrene foam	New	-	-	11 lb 14 oz	-	-
polystyrene foam	New	-	-	11 lb 12 oz	-	-
polystyrene foam	New	-	-	11 lb 14 oz	-	-
polystyrene foam	New	-	-	7 lb 10 oz	-	-
polystyrene foam	New	-	-	7 lb 12 oz	-	-
stic bag	New	-	-	-	-	-
stic bag	New	-	-	-	-	-
stic bag	New	-	-	-	-	-
.	New	-	Passed	17 lb 0 oz	-	-
.	New	-	Passed	16 lb 6 oz	-	-
.	New	-	Passed	15 lb 10 oz	-	-

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The loss of buoyancy with age can be examined if the age of the PFD is plotted against the amount of buoyancy left in the PFD (Figure 6-1). Although only a limited amount of data has been collected, a trend is noticeable. Since most of the tested PFDs were in the first two years of usage, we will compare the first and second year. These show that the mean buoyancy from the first to second year has decreased by 0.39 lb. If we assume that the mean buoyancy decreases by this same rate each year, the mean buoyancy of PFDs would be below the minimum of 15.5 lb by the fifth year. The test results for the three-year-old PFDs show a mean buoyancy of only 13.09 lb, suggesting that the life of these PFDs may be considerably less than five years, and that the loss in buoyancy per year may not be constant. The information that was available on PFD histories was not complete enough to draw firm conclusions on usage and environmental stressors as factors in PFD aging. During the next phase of testing, used PFDs from the general public and accelerated aging tests will provide more complete PFD histories from which to discern possible usage and environmental factors affecting PFD degradation

Besides loss of buoyancy, zipper failures were also noted as being a significant failure mode. For instance, eight of the Type III devices were found to have malfunctioning zippers. Zipper malfunctions were classified as any failure whereby it is impossible to fasten the zipper. These were caused by zipper being ripped away from jacket, zipper pull is broken off or broken zipper teeth. The loss of the zipper can seriously reduce the effectiveness of the PFD.

6.3.2 New PFD Test Results

The more surprising part of this study was that out of 62 new PFDs tested, 19.4% failed the initial buoyancy test. When a sample of 14 out of 49 that passed the first test were submitted to a 24 hour submersion test and then retested, three additional failures were observed and if this is projected onto the remaining 49, the percentage of failures rises to 35% (Figure 6-2). The problem of new PFDs failing initial buoyancy tests is one that quite obviously centers around design and manufacturing. With a failure rate being virtually equivalent to the used PFD failure rate, it is obvious that this problem must be resolved before any satisfactory program on used PFD reliability can be effective. The nature of this problem seems to lie with quality control in manufacturing or possibly with flotation materials used. If failure percentage by manufacturer is plotted, it shows that one manufacturer has the majority of the failures (Figure 6-3). Also, if

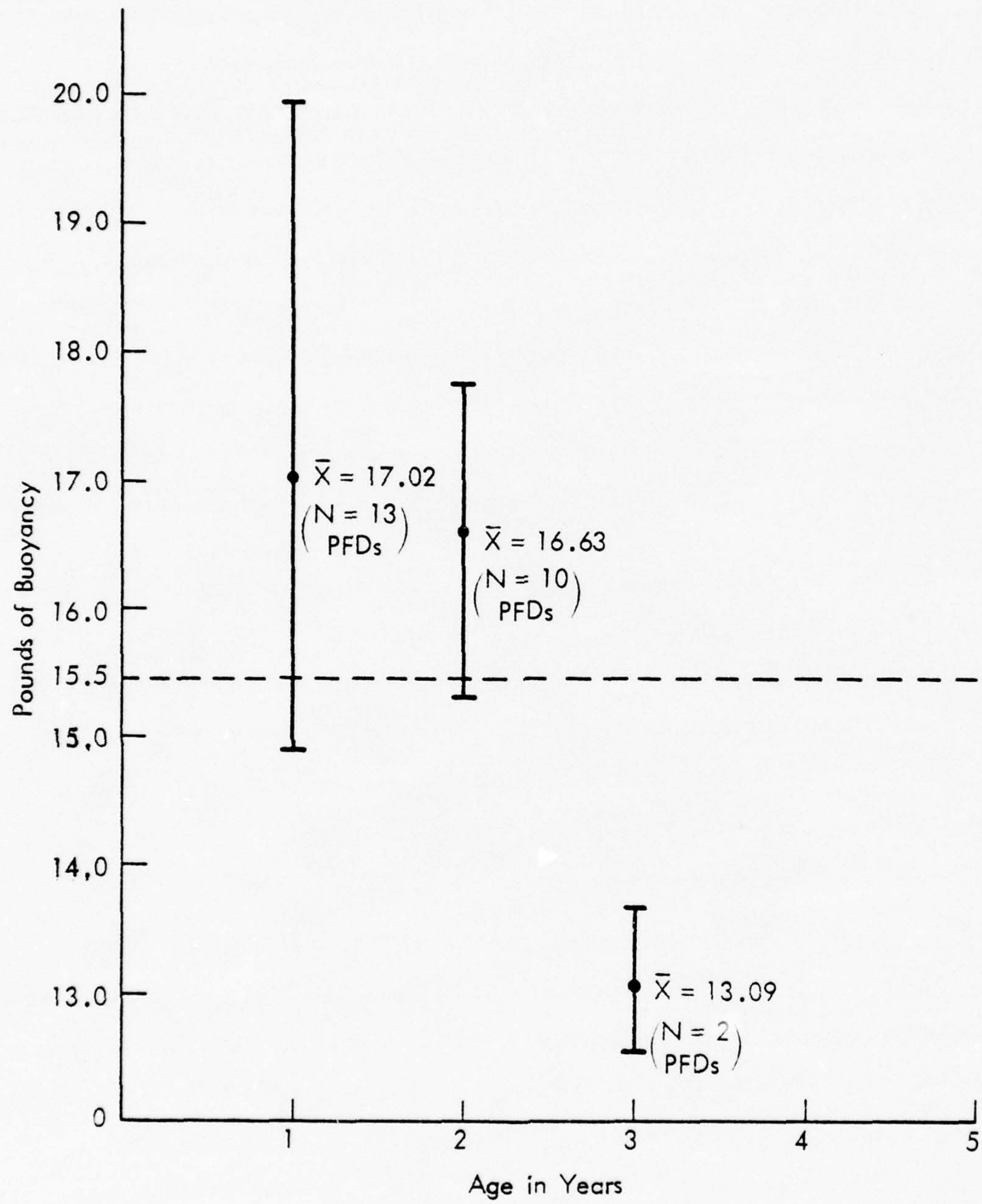
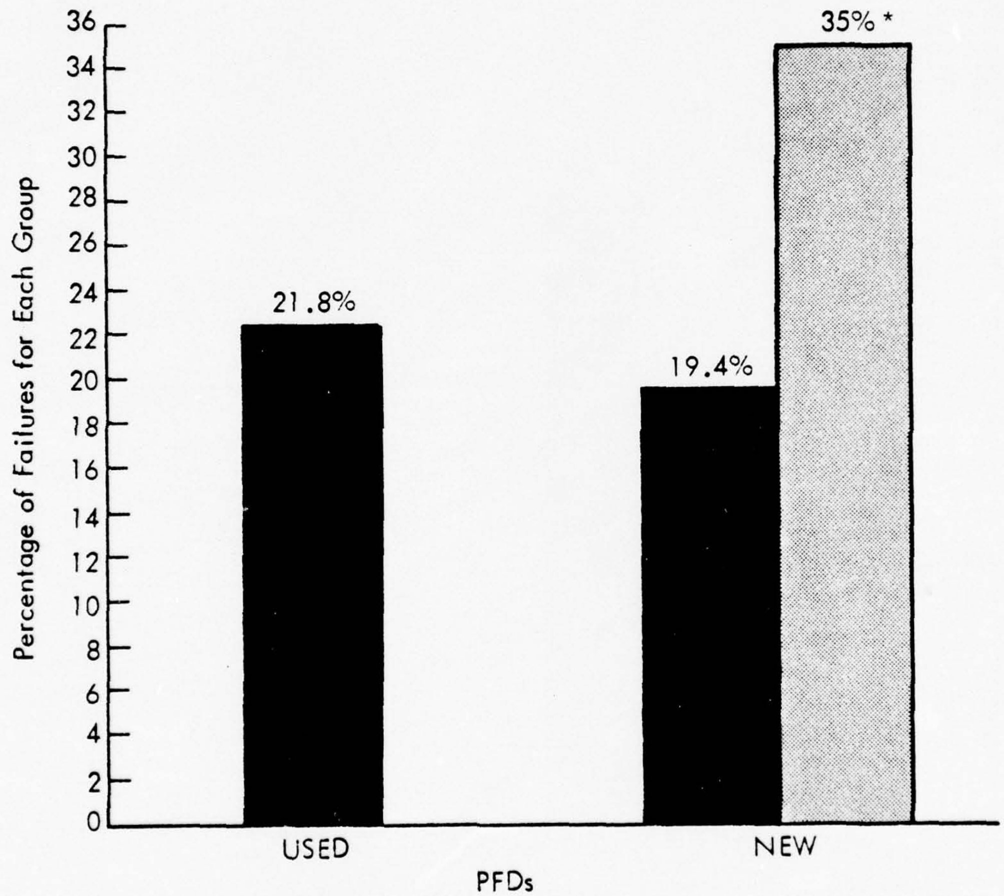


FIGURE 6-1. BUOYANCY AS A FUNCTION OF PFD AGE



* Note: After submersion testing, failure percentage was found by projecting the three additional failures found from testing 14 out of 49 to the remaining 49.

FIGURE 6-2. EFFECTIVE BUOYANCY TEST FOR 15.5 POUNDS

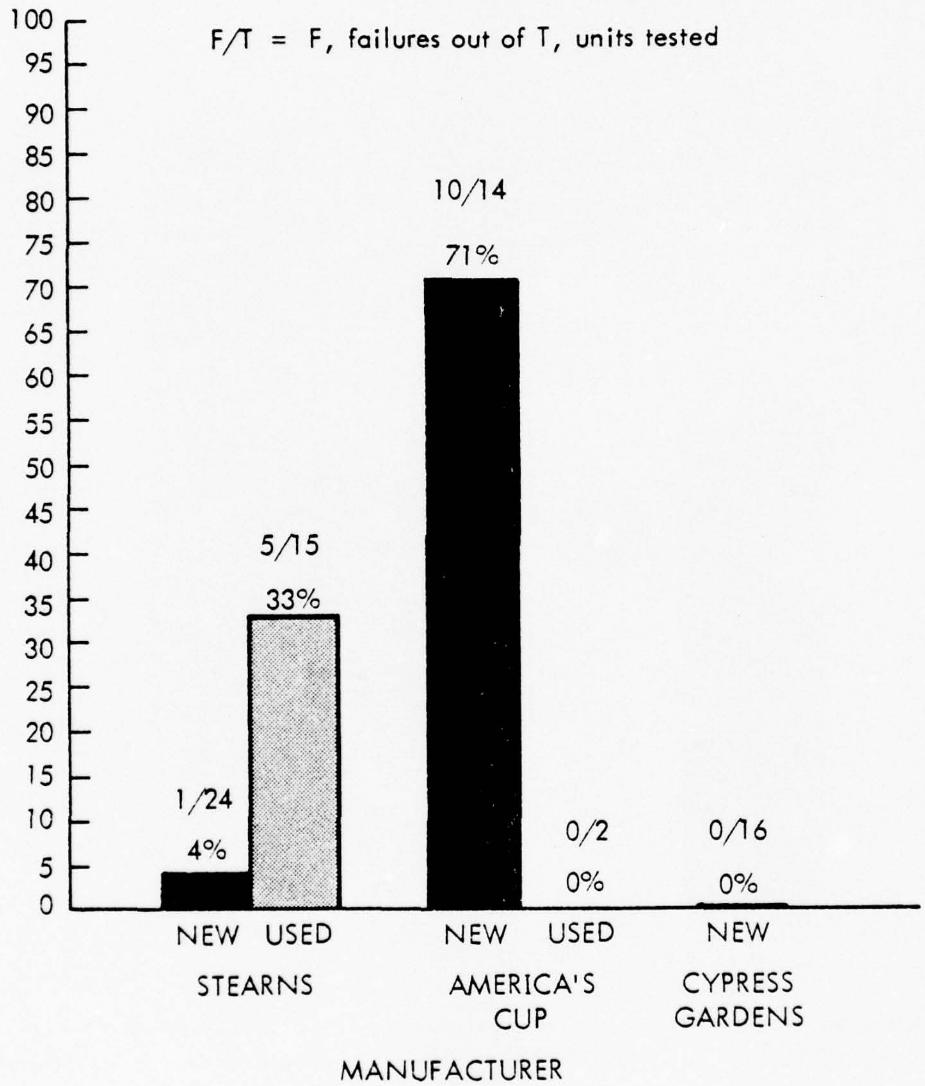


FIGURE 6-3. FAILURE PERCENTAGE BY MANUFACTURER

the dry weight of each of the new PFDs is examined (Table 6-2), we can see that PFDs weighing less had a much higher (64%) failure percentage than the heavier PFDs. Upon examining the size (small, medium, large, and X-large) of the PFDs for the same manufacturer vs failure percentage, we find that all medium size PFDs passed while all large and X-large PFDs failed the same test. These three factors lead us to believe that a quality control problem, such as the amount of flotation material used, is a leading cause in these PFD failures. These suspicions were confirmed for this particular manufacturer. An investigation by the Coast Guard revealed that a layer of foam has been mistakenly left out.

TABLE 6-2. PFD WEIGHT (NEW) VS. BUOYANCY FAILURES

PFD DRY WEIGHT	NO. TESTED	NO. FAILED	% FAILURE
1 lb to 1 lb, 6 oz	14	9	64%
1 lb, 6 oz to 1 lb, 12 oz	8	1	13%
1 lb, 12 oz to 2 lb, 1 oz	35	1	3%
>2 lb, 1 oz	5	0	0%

An analysis of the results from the fourteen new PFDs that were selected for 24 hour submersion and subsequent buoyancy testing showed that all the failed PFDs were from the same manufacturer, were Type III and all used the same type of flotation material. If the dry weights of the failed vs. passing PFDs are compared, there is no difference found between weights, thus leading us to suspect that the problem may be the type rather than the amount of foam used. In other words, the foam is losing buoyancy with extended water exposure.

Several possible causes for these failures can be suggested. For instance, it is possible for the manufacturer to reduce or not control the amount of flotation used in assembly of PFDs and this defect go undetected. Also, different types of PVC foam have been used by the same manufacturer on the same model which would alter the results. To avoid this problem, all flotation materials should be put through long term water submersion testing. An examination of quality control methods is also recommended.

6.3.3 Summary

These initial results point up two major problems with PFD reliability: quality control in manufacturing covering the amount and type of buoyant foam used and the effects of aging and stressing.

The results of the section on new PFD testing point out the necessity to consider problems with quality control before we can consider the problem of PFD degradation with use. It would be impossible to recommend satisfactory PFD standards for time and usage if we are unsure of the initial performance of new PFDs. Wyle's initial tests have pin-pointed problems dealing with the buoyant materials. For instance, it was noted that the amount of buoyant material varied quite radically between PFDs and that some buoyant materials exhibited less buoyancy after 24 hour submersion testing.

The results from initial testing on used PFDs indicates a potential buoyant material degradation with age and potential problems with component failures such as zipper malfunctions. The initial results indicate a general loss of PFD buoyancy with age such that the average PFD would fail to pass minimum buoyancy requirement after five years. The data was insufficient to establish any correlation between particular environmental stressors and PFD degradation. The major part of this data collection will be performed in the next phase of research where detailed PFD histories will be obtained.

6.4 CONCLUSIONS AND RECOMMENDATIONS

The results of our previous research have pointed out that some problems exist with PFDs now in use. We have shown that PFDs degrade rapidly with age but have not yet identified what is causing this degradation. Some factors that appear to be particularly relevant are:

A. Environmental stressors
   1. Amount of sunlight exposure
   2. Temperature extremes
   3. Humidity extremes
   4. Water type - fresh or salt water

B. Usage stressors
   1. Frequency and duration of use
   2. Type of use - skiing, cruising, swimming, or fishing
   3. Type of storage - in what condition (wet or dry) and where

The initial problem is one of gathering data on PFD usage in the normal boating environment so as to determine which of the factors and to what extent each is contributing to PFD degradation. Three methods have been selected to collect this normal aging data.

6.4.1 Normal or "Real World" Data Collection

1. Wyle Aging Program — The first method involves the use of Wyle employees as subjects. A small sample of new PFDs has been made available to Wyle employees to use on weekends and vacations. Every time a PFD is used, a detailed questionnaire is filled out by the person as to the extent and nature of usage. At the end of every three months, these PFDs are put through Wyle's Reliability Test Program (see Methods of Approach). From this data, a failure mode frequency can be obtained for each type of failure mode. From the total population exposure time and the number of failures occurring during that time, a population failure rate can be estimated.

2. <u>Exchange Program</u> — A cross-section of the boating population will be established by the selection of several data collection sites across the country. Once a sample of boaters is established that expresses interest in the project, subjects will be asked to exchange any used PFDs that they have for new and pre-tested PFDs. In addition to exchanging of PFDs, the subjects will be required to fill out detailed questionnaires on the used PFD histories.

3. <u>Public Aging Program</u> — These same subjects will then be asked to keep detailed histories on these new PFDs that they are given. After a certain period of time (about six months), the PFDs will be tested for buoyancy (on-site testing), visually inspected for other failures, and their histories collected. From this data, we will be able to determine the PFD buoyancy decrement and the stressors to which it was exposed. This program will be continued every six months for the duration of the study.

There are advantages and disadvantages inherent in all three collection methods. The main problem with the used PFDs collected from the exchange program is a lack of an accurate PFD history. For instance, we do not know whether the PFD performed up to USCG standards when new, therefore, we cannot be certain as to whether the PFD failure was due to usage and environmental stressors. However, this data does provide a good example of normal PFD usage in terms of activities and amount of usage. From this data we will be able to discern which environmental and usage stressors are most common and important. This information will help us improve the accelerated aging program (see discussion below).

Both the public and Wyle aging program have the disadvantage of taking a longer period of time to complete but will provide more accurate data on PFD usage and history. From this data, we will be able to correlate the actual PFD failure with the type of environmental and utilization stressors to which it is exposed.

These three phases of the program will eventually complement one another. The exchange program provides more immediate data but of a poorer quality while the public and Wyle aging program will give higher quality data but over a longer period of time.

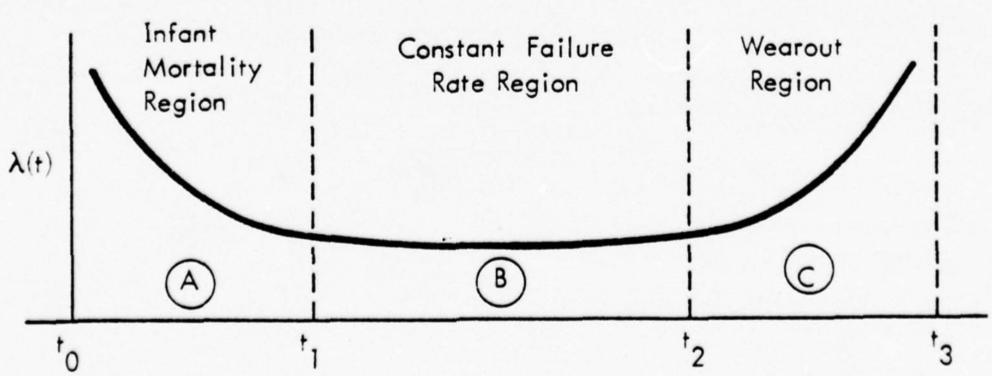
6.4.2 Accelerated Aging Program

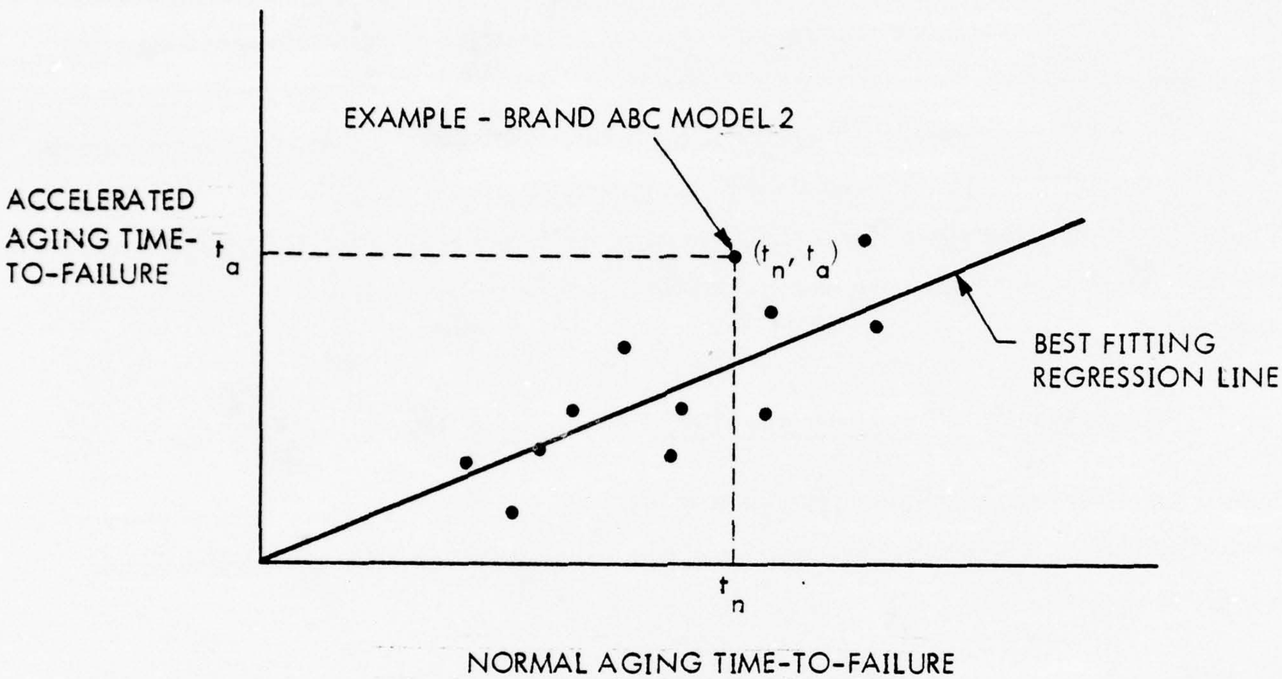
At the same time that normal aging data is being collected, alternate accelerated aging programs will be designed and implemented. These programs would be based on existing knowledge about PFD materials and on engineering judgement as to the effects of the accelerated stressors to be used. Using the information from these accelerated aging programs and data from the normal boating environment, the accelerated aging method that best corresponds to real world aging would be selected. The selection will be accomplished by plotting the accelerated aging time-to-failure for various accelerated aging methods against normally aged time-to-failure and fitting a regression line through the data (see Figure 6-4). The best method is that for which the data points show the least dispersion about the regression line (minimum residual variance).

6.4.3 Correlating Normal and Accelerated Aging Results

After establishing the accelerated aging method that best simulates the normal aging environment, this procedure will be applied to a sample of PFDs to determine their reliability over time and to establish a failure rate.

The failure rate will be established by testing a sample of PFDs in accelerated aging (the number of PFDs tested will depend on the confidence interval that is desired on the Reliability estimate) and determining the number of failed units for some unit time period. This number, which we will call λ, will be an average failure rate over the time period used. It is expected that the failure rate will be a variable function of time exhibiting what is conventionally known as the "bathtub curve."





NOTE: Each point is obtained by plotting the lives of a pair of PFDs of the same make and model, one subjected to accelerated aging and the other normal aging.

FIGURE 6-4. EXAMPLE GRAPH OF PLOTTING ACCELERATED TIME-TO-FAILURE VS. NORMAL TIME-TO-FAILURE FOR ONE ACCELERATED AGING METHOD

The reasons for us to expect the PFD data to follow such a curve are as follow:

- Region A is known as the infant mortality region. This part of the curve shows that as operating time increases, the failure rate decreases. The interval represents the period during which quality control problems such as assembly errors, defective parts and materials and other problems are found. Our initial test results have indicated that PFDs tend to follow this same pattern in early life.

- Region B shows that as operating time increases, the failure rate remains constant, or in other words the failures are due to the appearance of certain "random" disturbances. In our case, the failure rate is primarily due to the fact that a system such as a PFD has subsystems such as flotation, straps, etc., with varying sub-element failure rates. Some of these will have decreasing failure rates while others will have increasing failure rates. The net result is an observed constant failure rate for the PFD. This time period is known as the useful operating life of the item.

- Region C shows that as operating time increases the failure rate increases. This interval represents the wearout period during which age, deterioration, misuse, etc., cause the failure rate to increase.

Our previous discussion points out two problems with establishing a reliability indicator. Region A of our graph shows that manufacturing quality control presents a failure rate that must be dealt with separately from later failure rates. If the Region A failure rate were to be included in our calculation of an average failure rate for all three regions, then the reliability of PFDs would be very low. For this reason, the quality control in manufacturing of PFDs must be improved in order for a feasible reliability indicator to be established.

A second problem revolves around the question of what is an acceptable reliability goal for the manufacturer to strive toward and then how can these requirements be stated in terms so that the PFD manufacturer can translate them into adequate tests and quality assurance requirements. The results of our studies will address these problems.

The problem of establishing a useful life for PFDs is a simple matter of testing the data for the best fitting function. From these results, any long term trends in the data can be estimated.

For example, if after an examination of these functions the Weibull distribution seems to best model the expected failure rate, the following analysis would be performed. In order to determine the parameters of the Weibull function for failure rate, $Z(t) = \alpha B t^{B-1}$, we would plot log Z(t) vs. log t (see Figure 6-5). Taking the logarithm of the failure rate function:

$$\log Z(t) = \log \alpha + \log B + (B-1) \log t$$

results in a linear function of the form:

$$y = b + ax$$

where:

$$y = \log Z(t)$$
$$b = \log \alpha + \log B$$
$$a = B-1$$
$$x = \log t$$

The parameters α and B can be found from the slope and intercept of the best fitting linear function to the points in Figure 6-5. From this knowledge of α and B, it is a simple calculation to find the Reliability Index. In this case:

$$R(t) = e^{-\alpha t^{B}}$$

Using this result, the Reliability R(t) can be plotted as a function of both accelerated time and normal time.

The above procedures, which are outlined in Figure 6-6, will give us two major results:

1) the Reliability of the existing PFD population, and
2) the expected Reliability of any new PFDs that are introduced into the PFD Market.

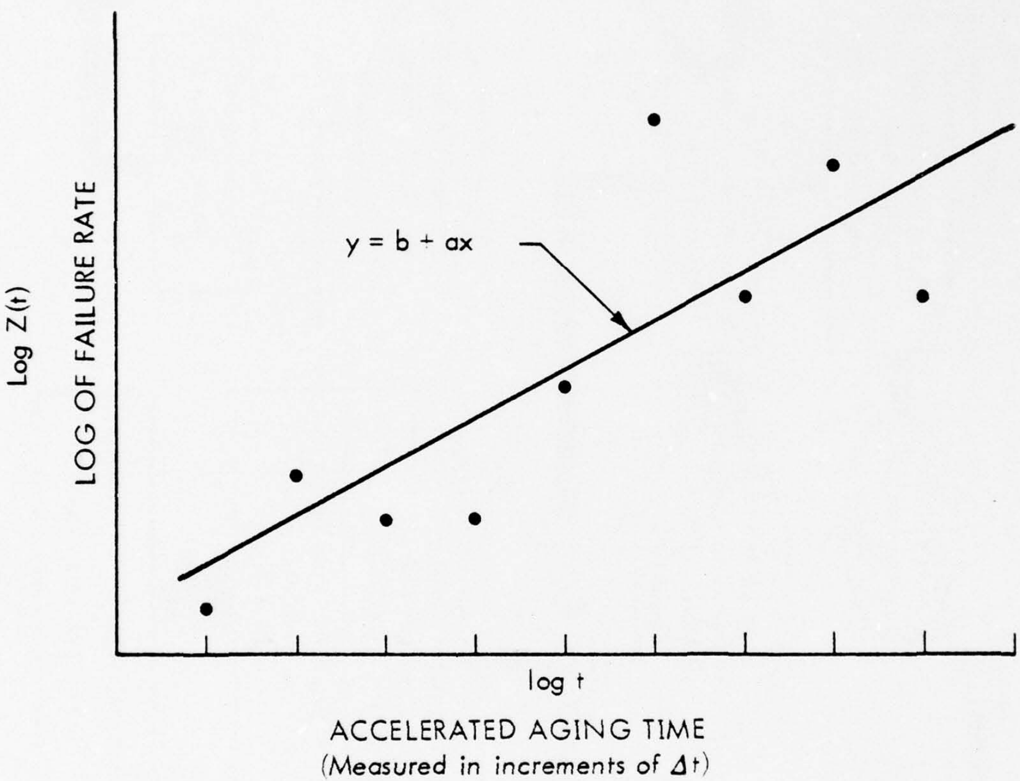

y = b + ax
Log Z(t)
LOG OF FAILURE RATE
log t
ACCELERATED AGING TIME
(Measured in increments of Δt)

FIGURE 6-5.

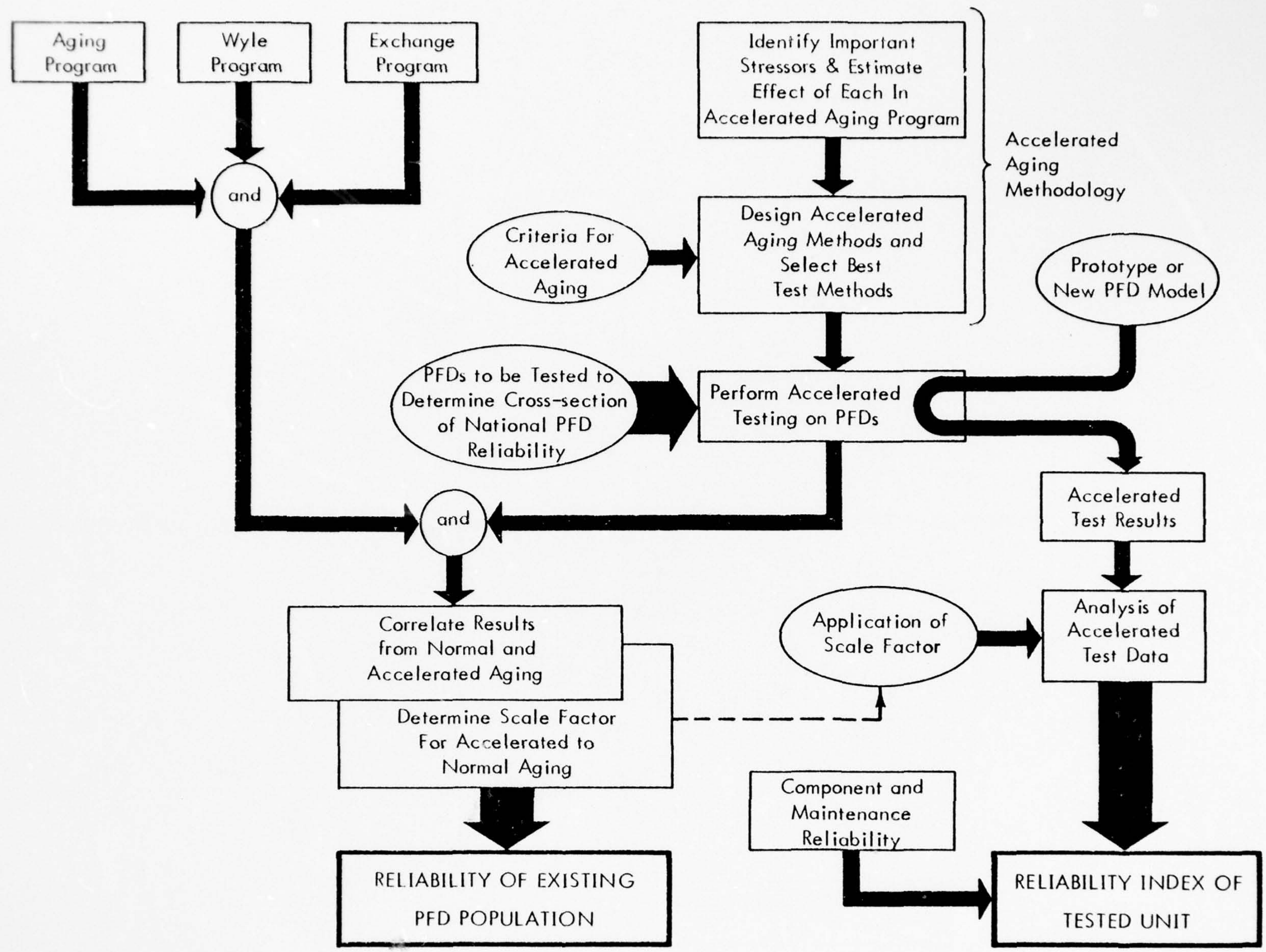


FIGURE 6-6. PROCESS FOR DETERMINING RELIABILITY OF EXISTING PFD POPULATION AND NEW DESIGNS

Adaptations to this program would be needed to test the reliability of hybrid and inflatable devices. A method would be needed to test the Reliability of components such as the inflation mechanism, the inner tube, and other human factors problems that would arise in any manually activated device. These items are now under further study and are discussed under Alternate Concepts.

APPENDIX 6-A. EFFECTIVE BUOYANCY TEST

1.0 SCOPE

A quick method was desired to determine whether a PFD had at least 15.5 lb of buoyancy.

2.0 PURPOSE

This test will verify whether the PFD to be tested has the 15.5 lb of buoyancy required.

3.0 BUOYANCY TEST

3.1 The PFD under test shall not be physically altered in any way to change its characteristics.

3.2 Perform this test in the convenient body of water.

3.3 Install the test PFD on the test form shown in Figure 6A-1. Adjust PFD as required to form a snug fit, using its furnished hardware and fasteners. Record any difficulties encountered with this operation or any obvious failure modes (i.e., torn material).

3.3 Lower the unit under test slowly into the water in an upright position. Do not submerge unit at this time. Observe and record whether the test assembly retains a stable and upright position.

3.4 Submerge the PFD under water for a two minute soak period. Move the PFD to and fro to remove any entrapped air, but do not squeeze or compress it. Observe and record any leaks in material when appropriate.

3.5 After two minute soak period, allow test unit to set free in the water and observe whether the unit sinks or floats. Record as pass or failure.

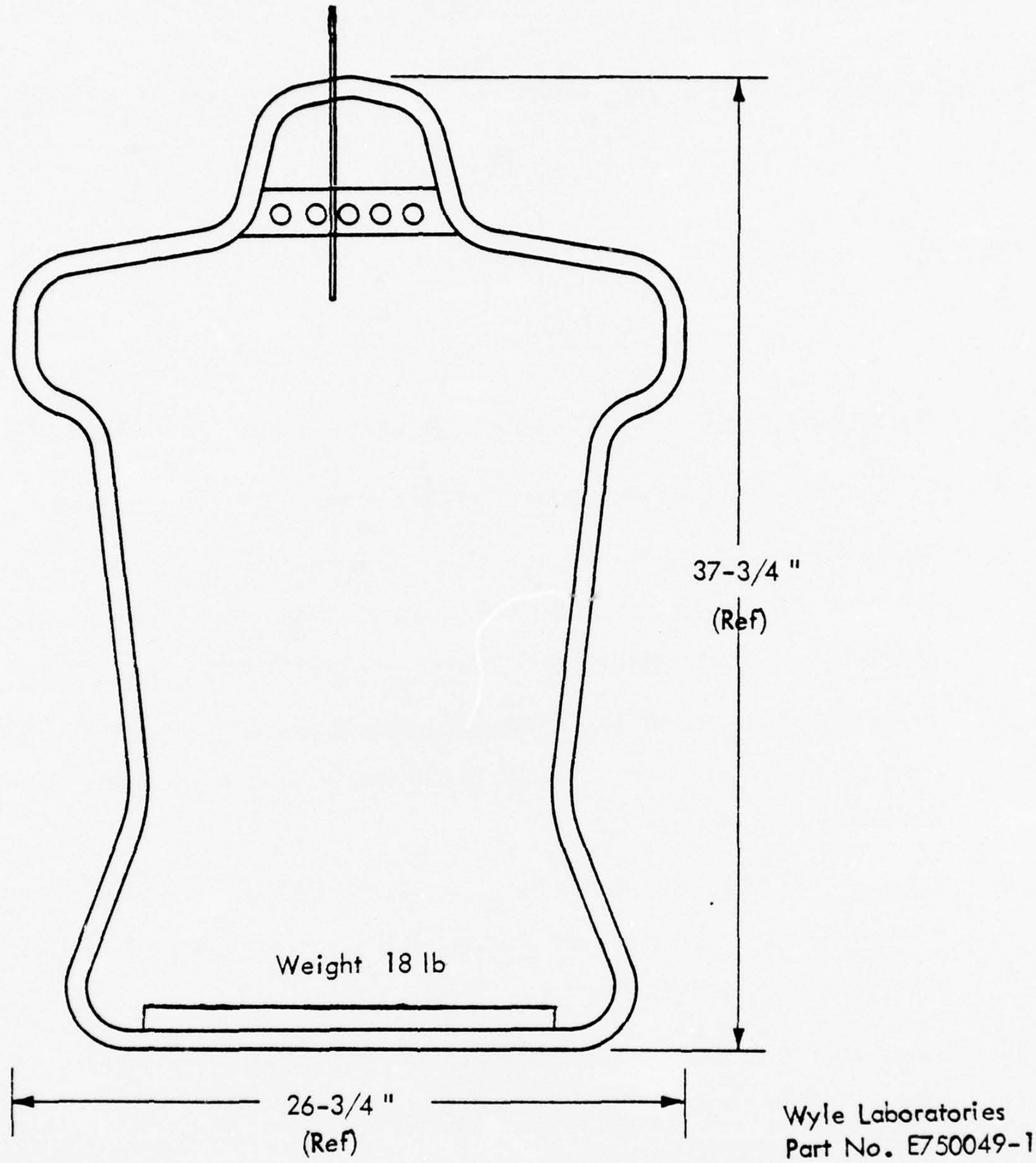


FIGURE 6A-1. BUOYANCY TEST FORM

APPENDIX 6-B. INCREMENTAL BUOYANCY TEST

1.0 SCOPE

A method is required to measure the exact amount of buoyancy that a given PFD possesses.

2.0 PURPOSE

This procedure will be used to determine by how much a PFD is above or below the required buoyancy. This procedure will also be used to determine the amount of buoyancy loss with age.

3.0 BUOYANCY PROCEDURE

3.1 Do not alter the PFD under test in any manner that will change its characteristics.

3.2 This test is to be performed in a tank of quiet water.

3.3 Install the test PFD on the lightweight test form shown in Figure 6B-1. Adjust and secure the PFD to the test form, using its furnished hardware and fasteners.

3.4 Lower the unit under test into the tank of water.

3.5 Submerge the PFD under test for approximately two minutes to allow any trapped air to escape.

3.6 Release and allow the unit under test to maintain a static position.

3.7 Add weights (see Table 6B-1) gradually (starting with the larger sizes) until the approximate buoyancy is reached, smaller size weights will be added (one to two ounces) until the PFD starts to sink.

3.8 Remove the test unit from the water. Add and record the total weights that were required to make the test unit sink.

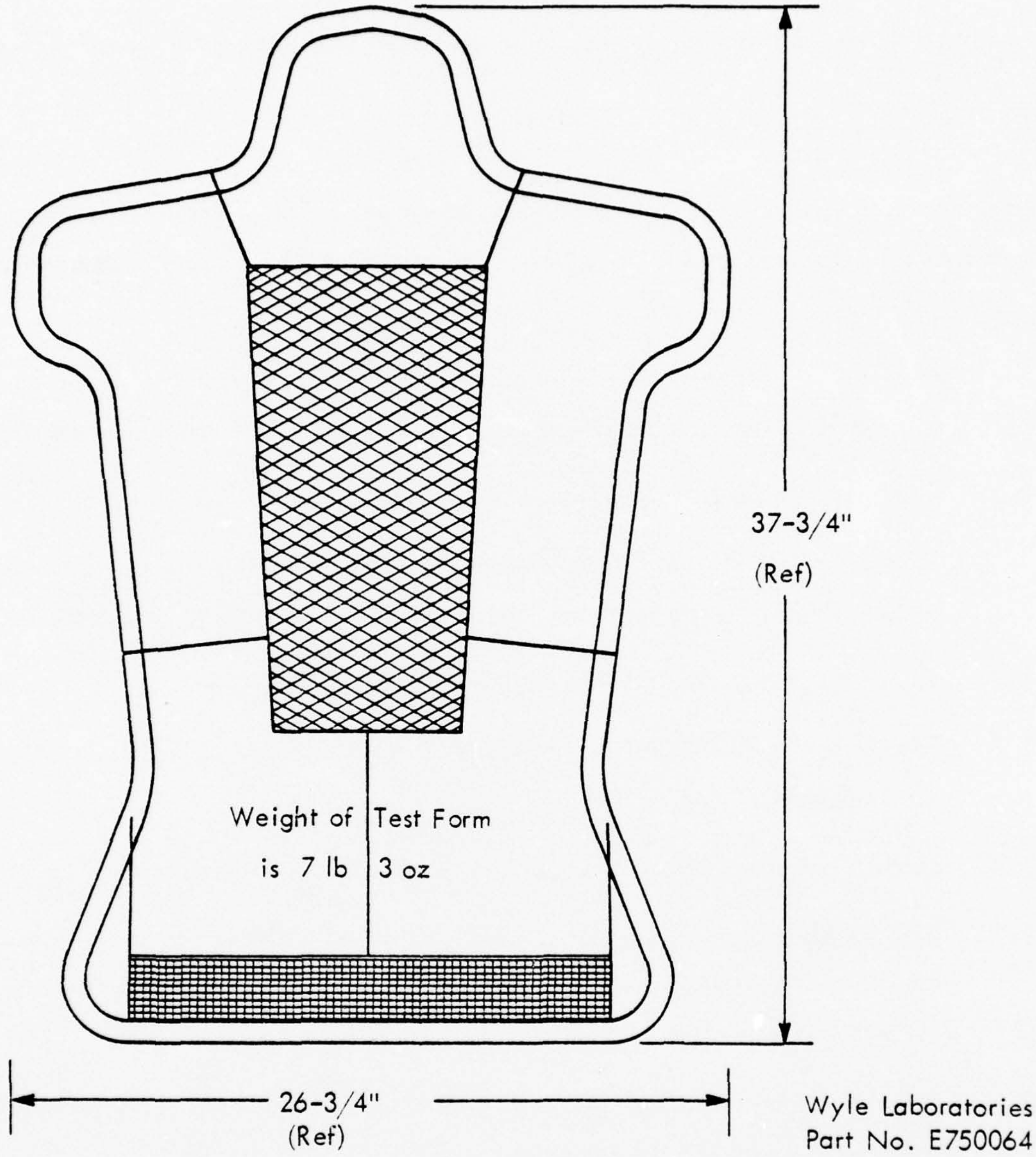


FIGURE 6B-1. BUOYANCY TEST FORM (LIGHT-WEIGHT)

TABLE 6B-1. WEIGHT OF TEST EQUIPMENT

Description	Weight In Air	Weight In Water
Test Form	7 lb - 3 oz.	5 lb
Lead Weight	4.4 lb	4 lb
Lead Weight	3.3 lb	3 lb
Lead Weight	2.2 lb	2 lb
Lead Weight	1.1 lb	1 lb
Lead Weight	8.8 oz	8 oz
Lead Weight	4.4 oz	4 oz
Lead Weight	2.2 oz	2 oz
Lead Weight	1.1 oz	1 oz

APPENDIX 6-C. SUBMERSION TEST

1.0 SCOPE

A method is required that would simulate extended use of a PFD.

2.0 PURPOSE

This procedure would be used to determine the water absorption characteristics of the PFD and thus subsequent effects on PFD buoyancy by determining buoyancy readings both before and after submersion testing.

3.0 SUBMERSION PROCEDURE

3.1 The PFD shall be subjected to the incremental buoyancy test (Appendix 6-B) to determine the actual buoyancy.

3.2 Do not alter the specimen PFD in any way to change its characteristics.

3.3 This procedure is to be performed by fitting the PFD to be tested on the test form, using all furnished sippers, straps, belts, ties, etc.

3.4 The complete test device shall be lowered into the water and weights added until the upper surface of the PFD is approximately two inches below the water surface.

3.5 The test device shall be secured in this position for a 24 hour period.

3.6 After this 24 hour period, the PFD shall again be subjected to the incremental buoyancy test (Appendix 6-B) to determine buoyancy decrement.

APPENDIX 6-D. IMPACT AND TENSILE TESTS

1.0 IMPACT TEST

1.1 Do not alter the PFD under test in any way to change its characteristics.

1.2 This test is to be performed using a suspended pendulum located over a tank of water.

1.3 Install and secure the test PFD on the test form (see Figure 6D-1) using all furnished zippers, straps, belts, ties, etc.

1.4 Install the test form containing the PFD under test onto the pendulum (see Figure 6D-2).

1.5 The pendulum is a hinged rod which willallow the test form to impact the water side ways in all five positions.

1.6 Raise the unit until the pendulum hook is 11.5 feet above the water line (see Figure 6D-2).

1.7 Release the test unit allowing it to impact with the water surface.

1.8 Remove the test form with PFD and visually inspect it. Record and photograph any damage or irregularities of the PFD.

1.9 Repeat 1.6, 1.7, and 1.8 with the test form containing the PFD in the other four positions as shown in Figure 6D-2.

2.0 TENSILE TEST

2.1 The PFD under test shall not be modified in any way to change its characteristics.

2.2 Secure the PFD under test to the tensile test fixture (see Figure 6D-3) using furnished zippers or belts or straps, but secure with only one closure method at a time for this test (see Figure 6D-4).

2.3 Apply a weight (gradually to avoid an unfair shock) to the lower cylinder attach point so that the total load (made up of the weight, lower cylinder, and attaching cable) is 300 pounds.

2.4 Paragraph 2.3 shall be performed on one closure at a time on PFDs containing multiple closure methods. Note and record type of closure tested.

2.5 The weight applied in Paragraph 2.3 shall be removed after a five minute period.

2.6 Inspect the PFD and record any damage found.

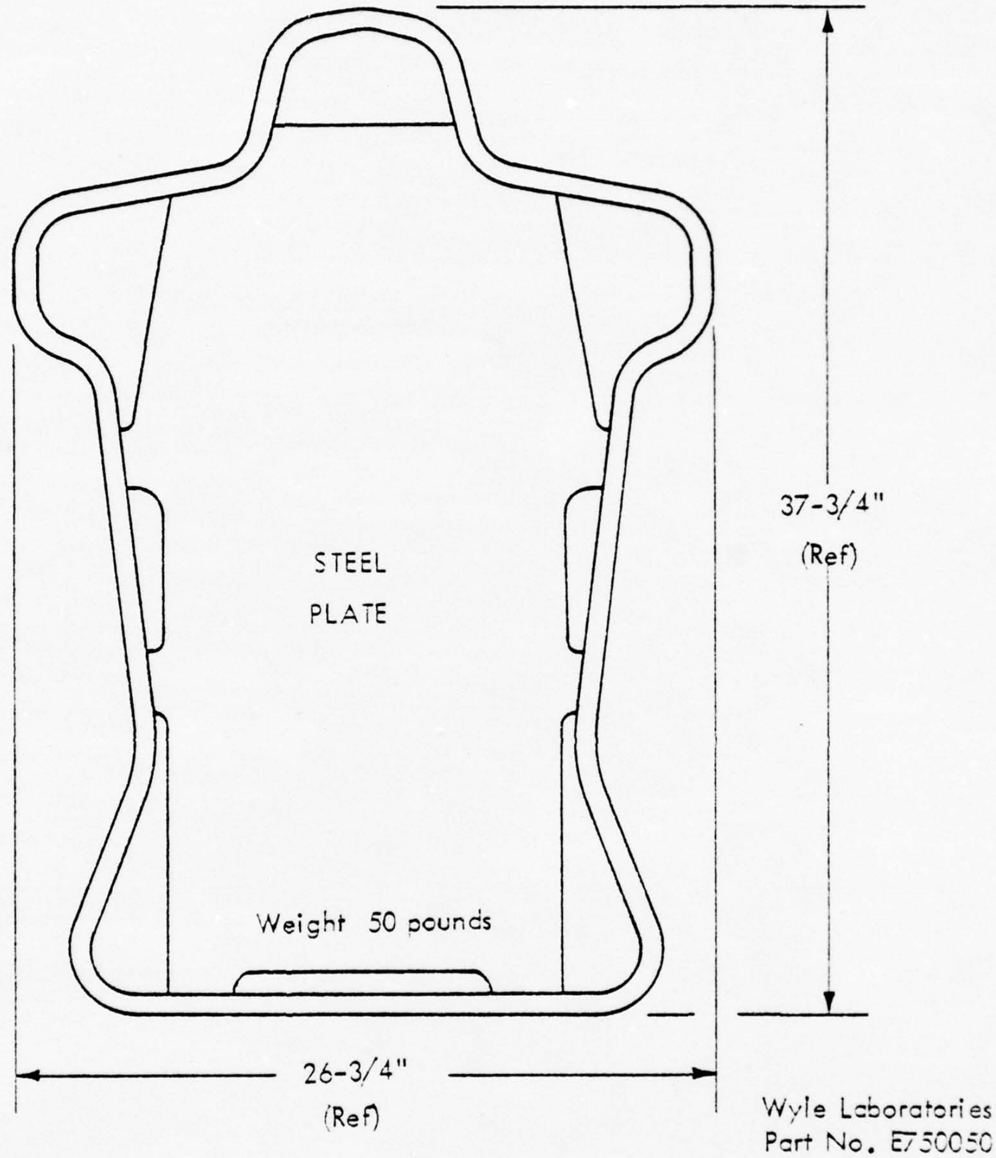


FIGURE 6D-1. IMPACT TEST FORM

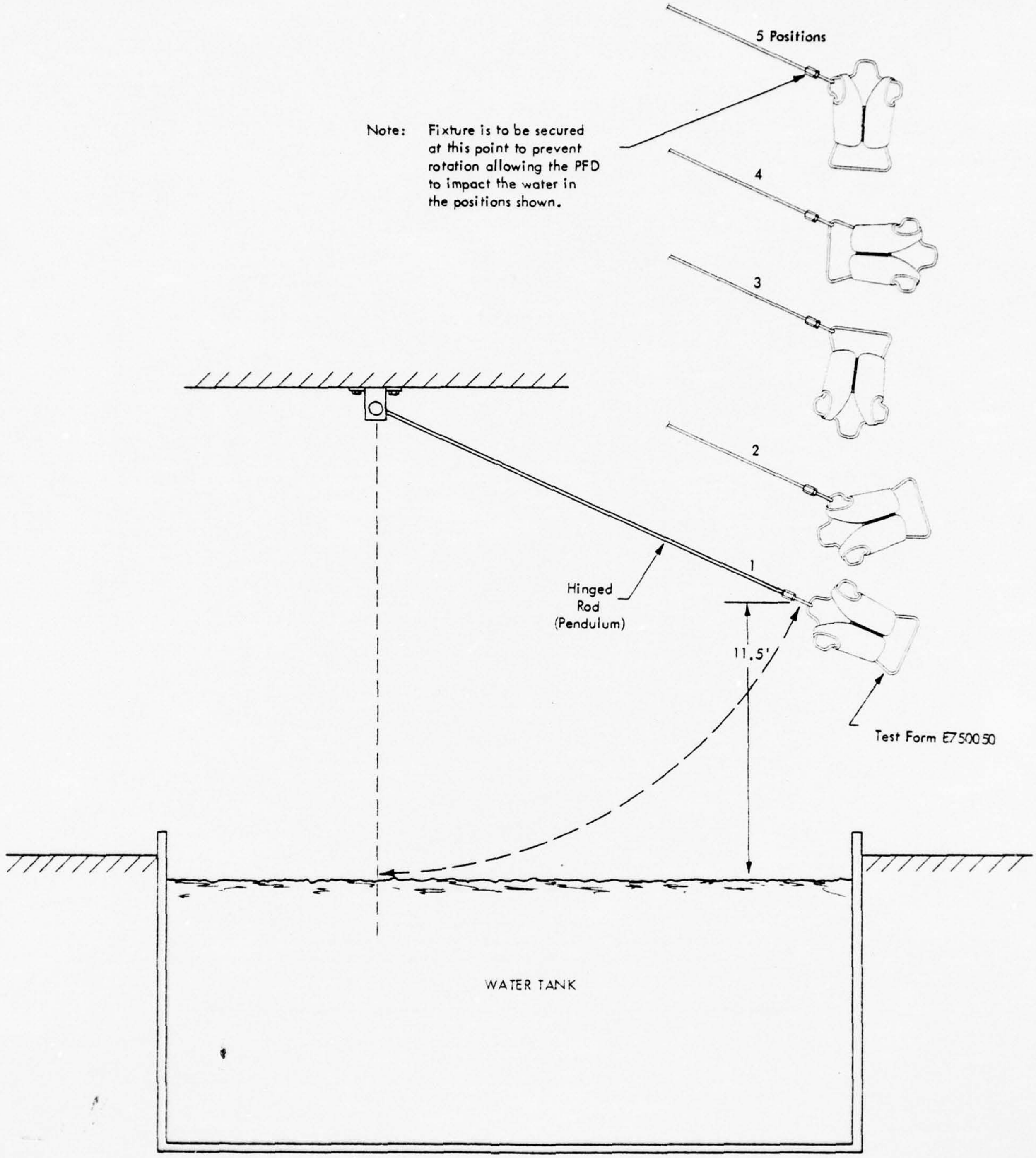


FIGURE 6D-2. IMPACT TEST APPARATUS

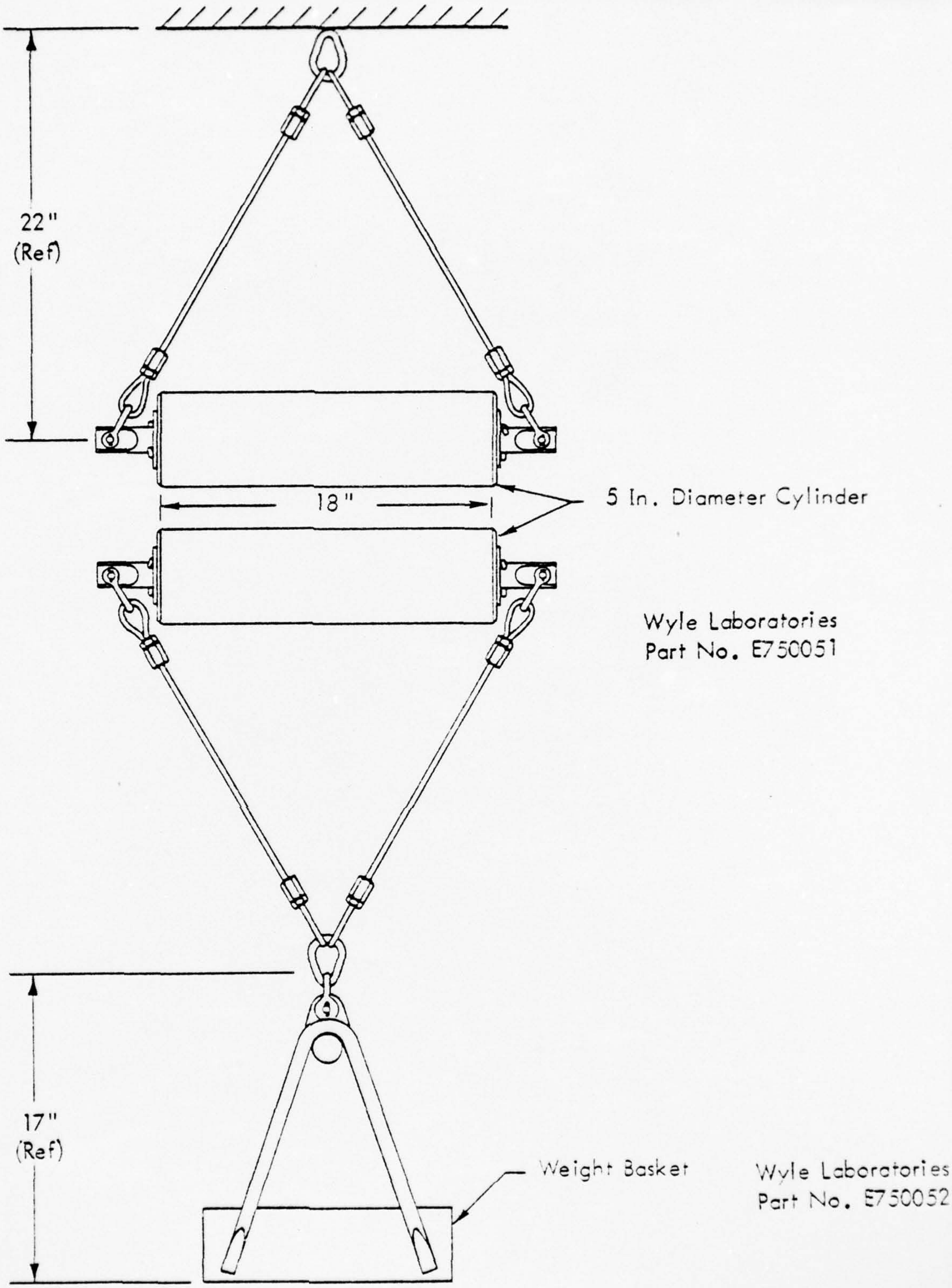
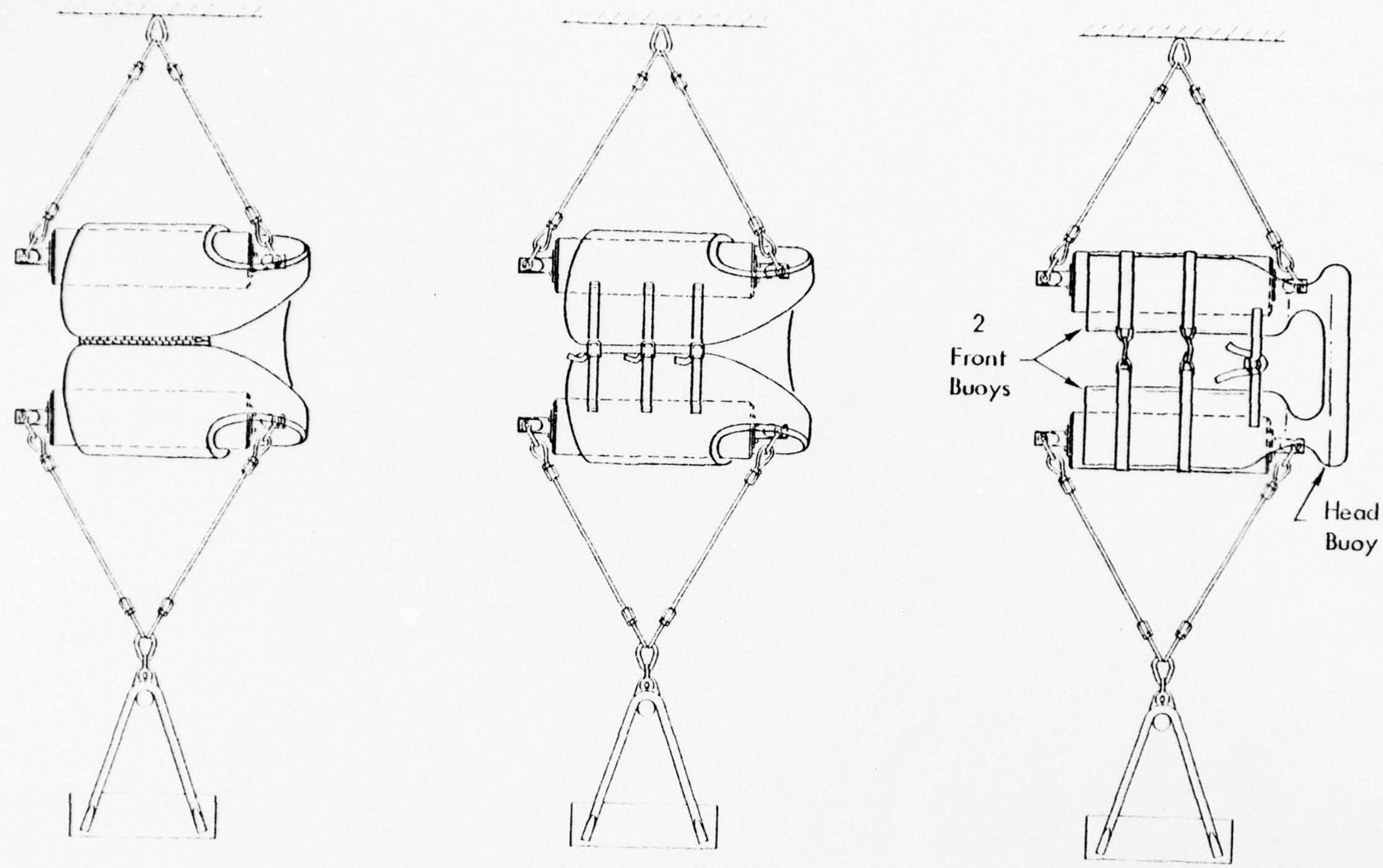


FIGURE 6D-3. TENSILE TEST FIXTURE



Vest with Zipper

Vest with Straps

PFD with Buckle and Strap

FIGURE 6E-4. METHODS OF USING THE TENSILE TEST FIXTURE

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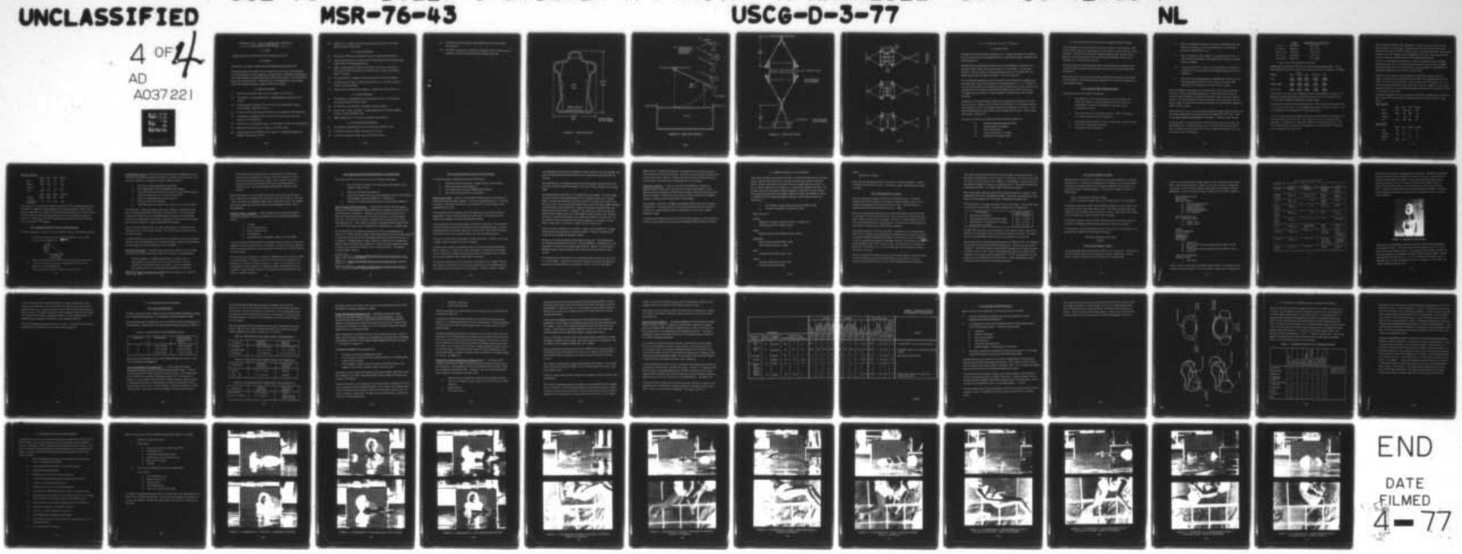

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APPENDIX 6-E. PFD ACCELERATED STRESSING AND AGING PROCEDURE

1.0 SCOPE

A method is required to accelerate the normal use stressing of new P FDs.

2.0 PURPOSE

This procedure will be used to perform both accelerated aging and stressing on PFDs.

The impact procedure will simulate a skier or swimmer hitting the water; the roller procedure will simulate trampling, sitting, transporting, and general abuse; the fastener exercise procedure will simulate fastening and unfastening the PFD; and the tensile procedure will simulate donning, pulling, and stretching the PFD. Accelerated aging will be performed by sunlight exposure, humidity and temperature extremes, and salt and fresh water exposure.

3.0 IMPACT PROCEDURE

3.1 Do not alter the specimen PFD in any way to change its characteristics.

3.2 This procedure is to ber performed using a suspended pendulum located over a tank of water.

3.3 Install and secure the specimen PFD on the test form (see Figure 6E-1), using all furnished zippers, straps, belts, ties, etc.

3.4 Install the test form containing the PFD under test onto the pendulum (see Figure 6E-2)

3.5 The pendulum is a hinged rod which will allow the test form to impact the water side ways in all five positions.

3.6 Raise the unit until the pendulum hook is 11.5 feet above the water line (see Figure 6E-2).

3.7 Release the test unit allowing it to impact with the water surface.

3.8 Remove the test form with PFD and visually inspect it. Record and photograph any damage or irregularities of the PFD.

3.9 Repeat 3.6, 3.7, and 3.8 with the test form containing the PFD in the other four positions as shown in Figure 6E-2.

4.0 TENSILE PROCEDURE

4.1 The specimen PFD shall not be modified in any way to change its characteristics.

4.2 Secure the specimen PFD to the tensile test fixture (see Figure 6E-3) using all furnished zippers or belts or straps (see Figure 6E-4).

4.3 Apply a weight (gradually to avoid an unfair shock) to the lower cylinder attach point so that the total load (made up of the weight, lower cylinder, and attaching cable) is 100 pounds.

4.4 The weight applied in Paragraph 4.3 shall be removed after a one minute period.

4.5 Add and remove the weight a number of times to simulate the donning, pulling and stretching a PFD goes through.

4.6 Inspect the PFD for possible failure modes (i.e., broken straps, torn material, etc.).

5.0 ROLLER PROCEDURE

5.1 This procedure is to be performed by placing the specimen PFDs on a concrete slab and running a steel yard roller over them.

5.2 Lay the PFDs on a concrete slab in the opened, face-down position.

5.3 Using a smooth, hollow, yard roller, weighing approximately 25 pounds, propelled manually, roll over the PFDs 15 times.

5.4 Repeat Paragraph 5.3 with the PFDs in the opened, face-up position.

6.0 FASTENER EXERCISE PROCEDURE

6.1 This procedure is to be performed with the PFD specimen installed on a man.

6.2 If the PFD is secured by a zipper, zip and unzip it 100 times.

6.3 If the PFD is secured by tie straps, tie and untie them 100 times.

6.4 If the PFD is secured by snaps or straps through buckles, fasten and unfasten them 100 times.

6.5 If the PFD is secured by any combination of the above, or by any other means not mentioned, secure and unsecure the means of fastening 100 times.

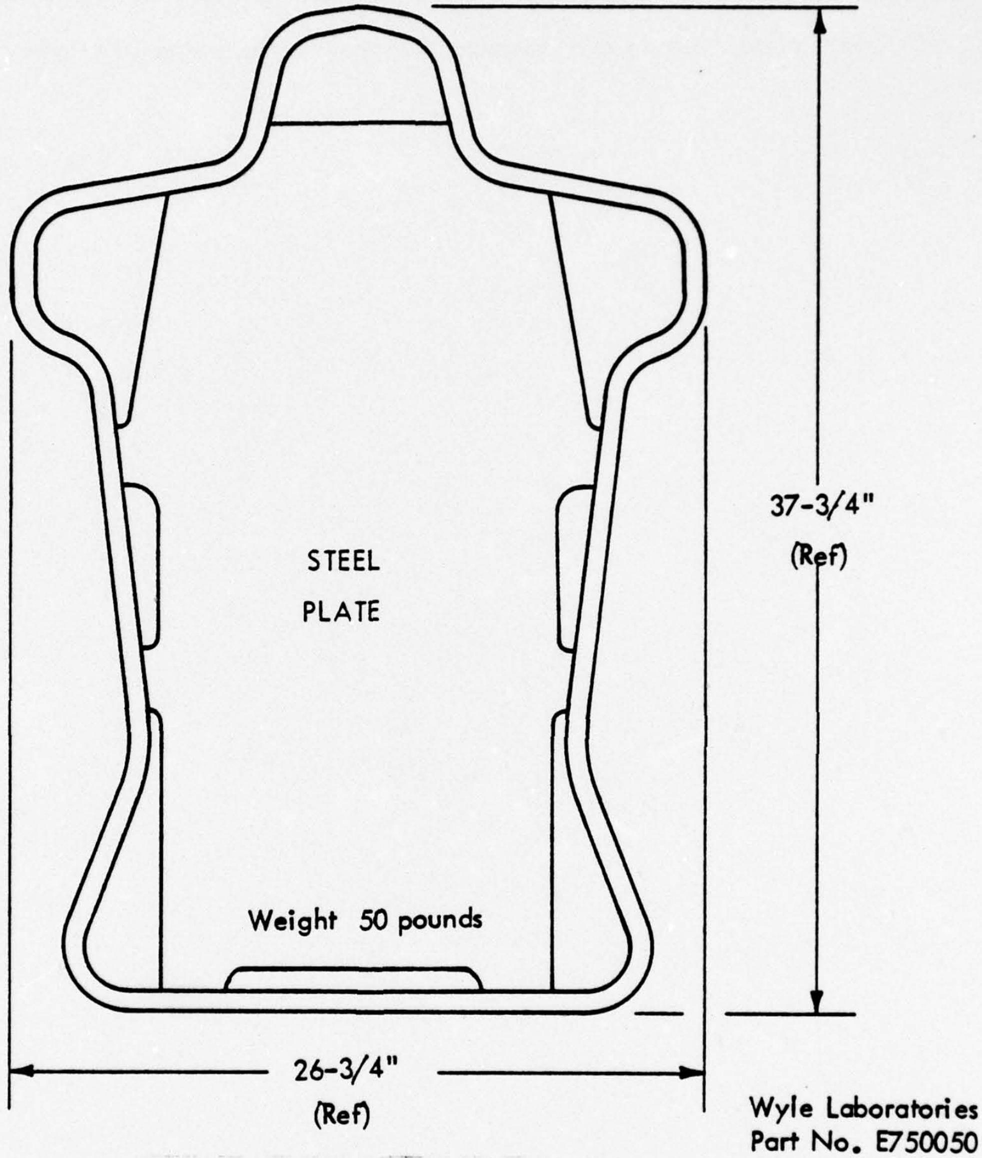


FIGURE 6E-1. IMPACT TEST FORM

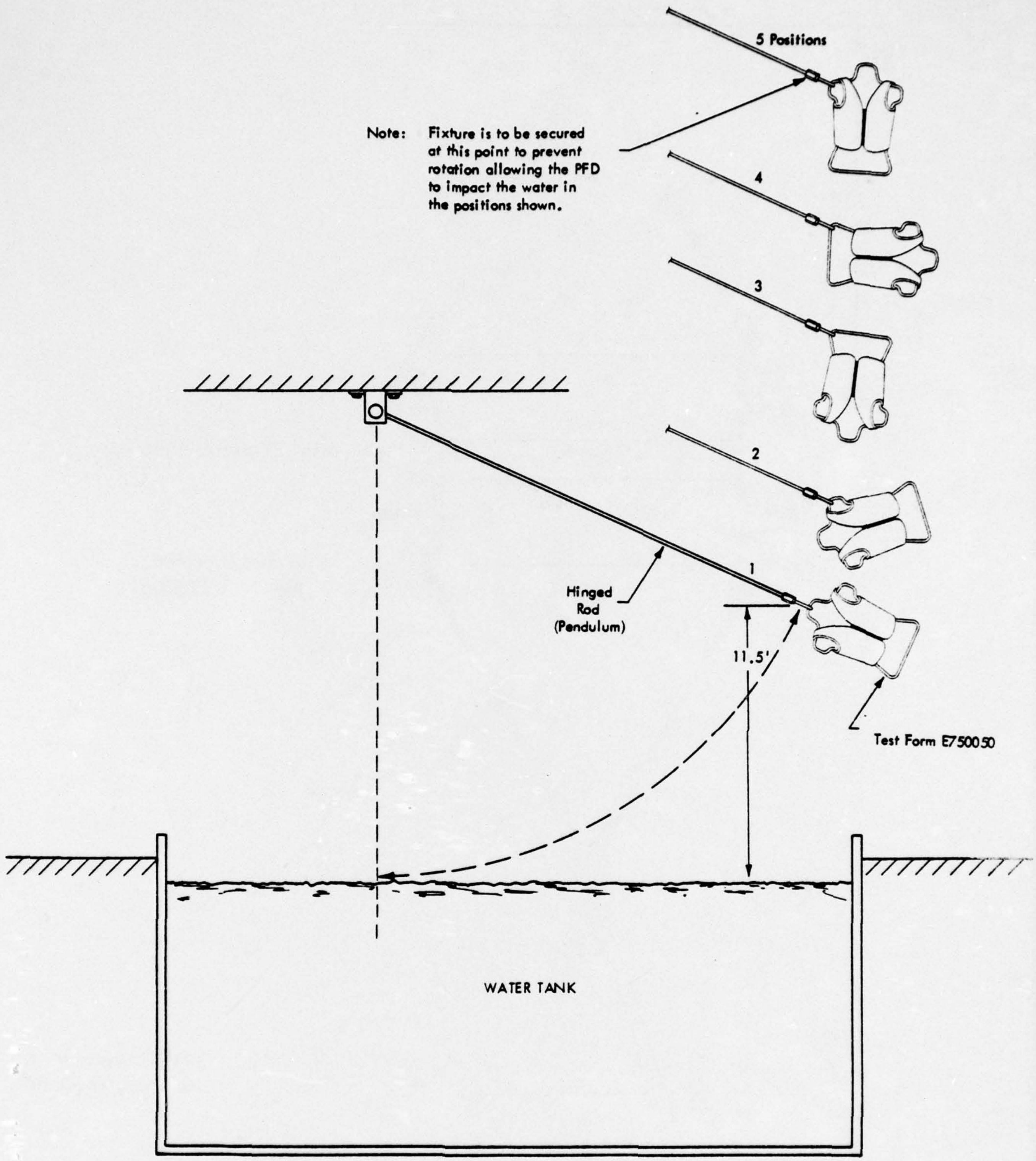


FIGURE 6E-2. IMPACT TEST APPARATUS

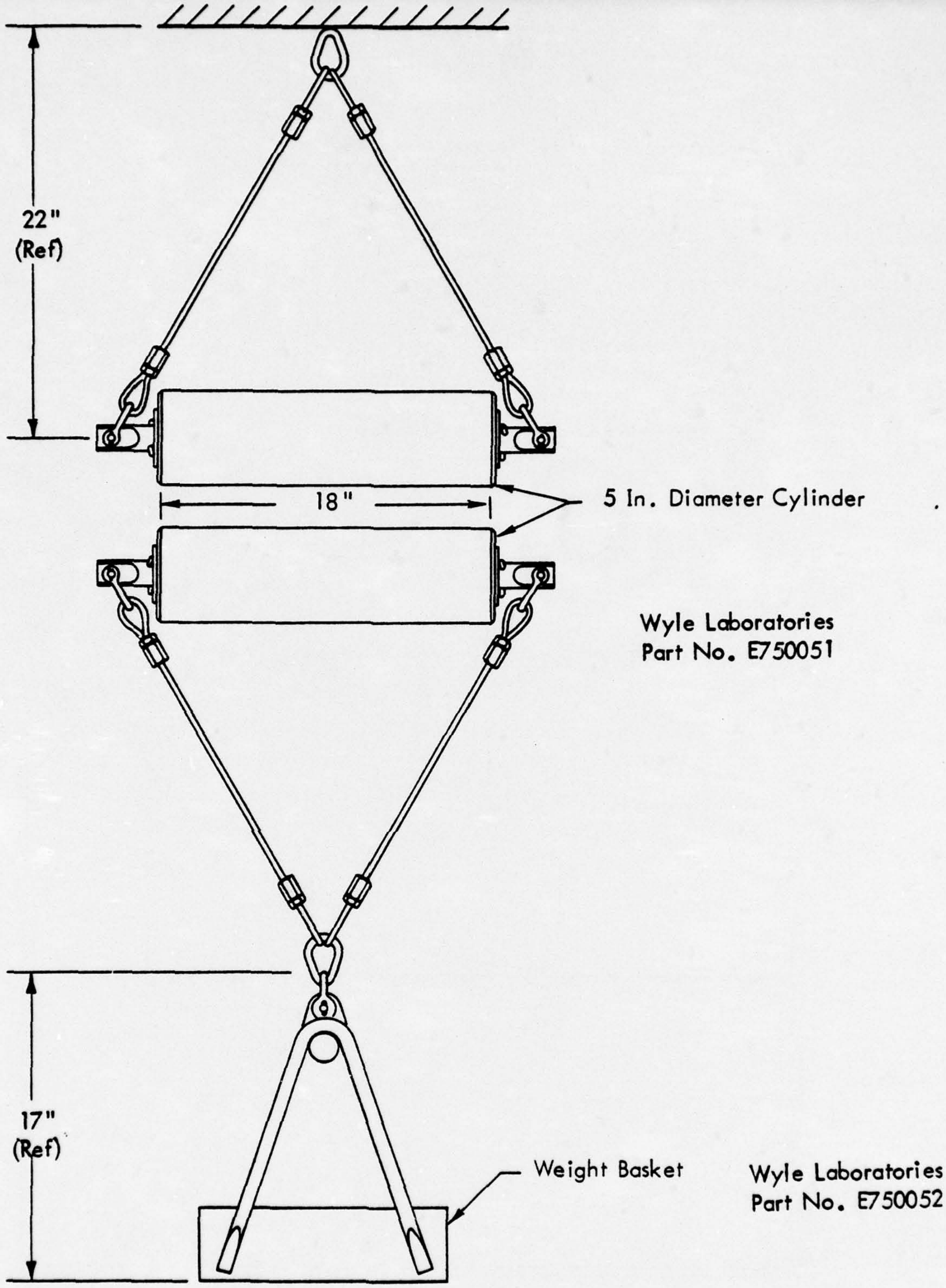


FIGURE 6E-3. TENSILE TEST FIXTURE

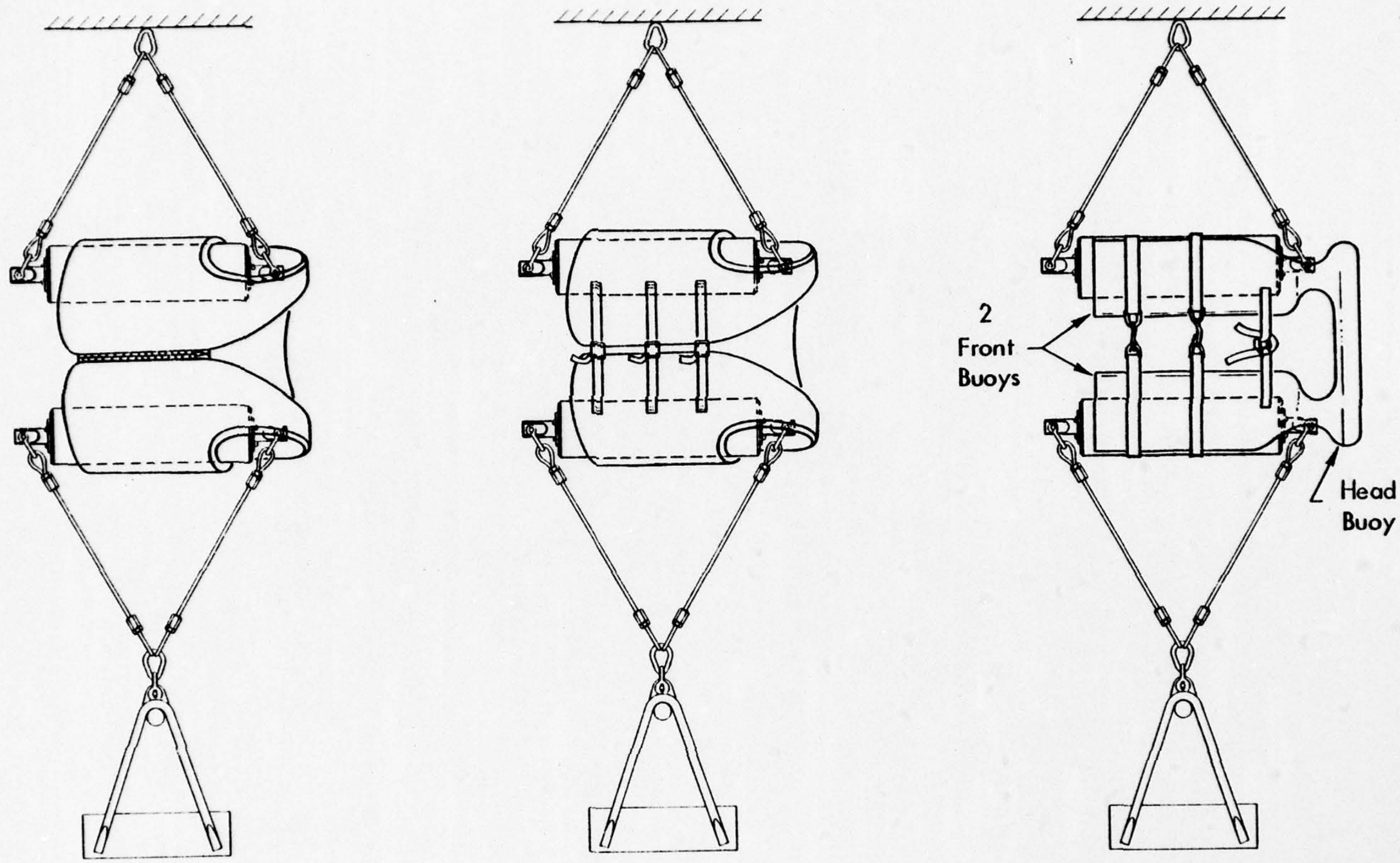


FIGURE 6E-4. METHODS OF USING THE TENSILE TEST FIXTURE

7.0 ALTERNATE DESIGN CONCEPTS

7.1 INTRODUCTION

The purpose of the alternate design concepts study is to investigate the generality and applicability of the LSI to currently non-approved PFDs which might become eligible for approval under changing regulations.

Inflatable PFDs and inflatable PFDs with some amount of fixed buoyancy (hybrids) are manufactured for foreign markets and as scuba diving aids within this country. Are they more wearable? Is there an inherent reliability problem associated with an inflatable PFD? Do foreign regulatory agencies approve inflatables? Under what conditions?

This list of questions represents but a few of the ones that were formulated at the beginning of this research task, and led to the formulations of the subtask objectives, i.e., (1) identify the functions that future PFDs can serve based on research findings, and (2) attempt to identify those characteristics that an alternate concept PFD should possess to fulfill those functions, and (3) compare these characteristics with those of presently available foreign made inflatables and hybrids.

Unfortunately, the foreign made hybrid PFDs that were ordered for the third part of the effort have yet to arrive. Therefore, tests to determine the characteristics of inflatables and hybrids were limited to two brands of inflatables available (but not approved) in this country. Three types of hybrid PFDs were constructed from these inflatables and were tested. Results of these tests are found in Section 7.4.

This section is divided into five parts which address the following objectives:

7.2	Identify functional requirements for PFDs
7.3	Examine foreign PFD standards
7.4	Tests of hybrid devices
7.5	Integrate requirements with designs
7.6	Recommend future research efforts.

7.2 IDENTIFICATION OF FUNCTIONS THAT ALTERNATE PFDS CAN SERVE

Current PFD regulations state that the device must have a certain minimum buoyancy. Additionally, PFDs of Type I and II are designed to turn an unconscious wearer's body over to face-up position. But PFDs built to meet current regulations apparently don't meet the boating population's criteria for a garment to be worn while boating; therefore, PFD wear rate is alarmingly low. (See Section 5 of this report.)

This section looks at the results of research efforts to date and summarizes those PFD characteristics that have been identified as being beneficial to wear rate, physical effectiveness, and reliability.

Many questions have to be asked of the available data before criteria for advanced concepts can be formulated. Those questions have been categorized and are listed at the beginning of each subsection below.

7.2.1 Inputs From ARM to Alternate Concepts

The following questions were asked of the ARM data:

1. How important is the self-righting feature of Types I and II PFDs? This relates to the number of unconscious people that enter the water while wearing PFDs, the length of time people are in the water, and the environmental conditions.

2. What is the importance of hypothermia protection in PFDs? This relates to environmental conditions and the exposure time.

3. How long are boating accident victims in the water prior to rescue? (or death)
4. What are the weather/water conditions?
5. How important is PFD accessibility?

6. What is the importance of automatic activation of inflatable devices? This relates to the number of unconscious people that enter the water and the projected inflatable PFD wear rate.

7. How much buoyancy is really needed? If we can get away with less, we might be able to make smaller, more wearable PFD; or perhaps even greater buoyancy is needed.

8. In conjunction with No. 7, above, is there any indication that hybrid devices with 5 to 7 lbs of foam and 10 lbs of inflatable buoyancy will or won't be effective?

9. What portion of the boating population needs PFDs most? What do we know about these people and their activities? What are the important PFD characteristics that would have led to their survival or rescue?

According to ARM, the percentage of the boating accident victims who enter the water unconscious is 1.4% or about 220 people annually. Of these 57.3% are recovered or, conversely, about 94 people die annually after entering the water unconscious in boating accidents. Of these 94 fatalities, 32 were wearing a PFD. Thus, assuming that wear rate does not change, the maximum potential benefit associated with the self-righting capabilities of PFDs is 32 lives annually.

ARM data show that, on an annual basis, about 243 people involved in boating accidents are in the water wearing a PFD for two hours or more and in below 61°F (18°C) water. These victims probably experienced hypothermia to some degree. Of these, 19 were fatalities.

According to ARM, most boating accident victims who enter the water are there for only a short period of time. The table below shows that, for victims whose time in the water is known, 75.3% are recovered or die within 5 minutes. Approximately 92.8% of the victims are rescued or die within 30 minutes.

	In Boat	Left Boat Or Thrown Out Of It
0 - 5 min	784 (99.5)*	2931 (92.5)
5 - 30 min	878 (99.4)	681 (91.8)
30 min - 2 hr	109 (91.8)	155 (97.4)
2 hr - 10 hr	125 (100.0)	127 (71.7)
N/A or Unk	3168 (99.7)	6113 (84.3)

* Note: No. of victims (probability of recovery)

Weather and water conditions x PFD wear rate was calculated and appears below. The top number represents the percent of total victims. The lower number is the probability of recovery.

	PFD				
Weather	Worn	Donned	Held	Not Used	Total
Calm	1.4 / 0.650	3.8 / 0.994	3.7 / 1.000	37.6 / 0.926	46.5 / 0.8925
Choppy/Rough	3.2 / 0.869	2.2 / 0.954	3.5 / 0.974	31.2 / 0.921	40.1 / 0.929
Swift Current	1.6 / 0.918	1.6 / 0.997	1.0 / 0.730	9.9 / 0.844	14.1 / 0.872

The data shows that the worn/calm configuration has the lowest probability of recovery. This phenomenon was discussed in detail in the benefit estimation section of this report (section 1.4) and is due to complicated interactions of accident factors.

No conclusion can be drawn from the data except that in those areas where the most data exists, i.e., in the "not used" column, the data appears to be as one would expect it should be. That is, the probability of recovery drops as the weather/seas worsen.

A look at the total column shows reported incidents to be almost equally divided between calm and rough/choppy/rough current waters. The numbers don't mean much though without exposure data. A boater may be in calm water for 90% of his boating exposure time. If that is true an equal amount of accidents may be happening in the remaining 10% of his exposure time that happens to be in rough water.

ARM can predict the benefits of PFD accessibility. There seems to be significant benefits from all combinations from PFD use. ARM projected 1185 victims donned a PFD after they entered the water and 1164 (98.3%) of them survived. ARM also projected 4016 victims entered the water with no PFD accessible with only 3488 (86.9%) surviving. There were over 5,000 unknowns. Therefore, ARM results show that PFD accessibility is important.

If we can link the importance of automatic activation to the number of unconscious people entering the water who are not currently being recovered we can say that there are approximately 100 people each year who could be saved by wearing a hybrid or inflatable PFD with self-righting capabilities and an automatic inflation feature.

ARM results were of no help in answering questions concerning the amount of buoyancy needed. We can stretch the results somewhat and consider that since ARM showed that most deaths occur in the 0 to 5 minute range, fatigue related to lack of PFD buoyancy (i.e., individual becoming fatigued by having to tread water) may not be a problem. In fact, a small amount of buoyancy on a very wearable and therefore commonly worn PFD could be instrumental in saving many of those victims.

ARM projected populations of victims using and not using PFDs, but doesn't give us information about important PFD characteristics that would have led to his survival or rescue. It does tell us:

Didn't Use PFD

	Adult	Teen	Child	Unknown
Male	7729	1308	250	228
Female	1785	511	233	50
Unknown	0	139	0	163
Total	9514	1958	483	441

Held The PFD

	Adult	Teen	Child	Unknown
Male	767	0	0	0
Female	474	50	0	0
Unknown	0	0	0	0
Total	1241	50	0	0

PFD Worn or Donned

	Adult	Teen	Child	Unknown
Male	1062	319	73	58
Female	283	200	41	83
Unknown	0	0	0	0
Total	1345	519	114	141

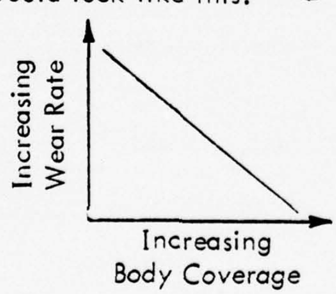
	Adult	Teen	Child	Unknown
TOTALS	12100	2527	597	582
% Wearing or Donning	11%	21%	19%	24%

When swimmers vs. non-swimmers are added to the figures we find that "adult/male/non-swimmers/didn't use" represent a very low probability of recovery group (28%), as does "adult/female/swimmer/didn't use" (78.8%) and "adult/female/swimmer/used not worn (held)" (73.4%). Most of the deaths are adult males because most of the victims are and because most of the boaters are. Children not using a PFD have probability of recovery of 0.90, but there were not many data points in that category.

7.2.2 Inputs From Wearability Studies to Alternate Concepts

The following questions were asked of the Wyle wearability study and other wearability studies:

1. Is it possible to construct a body coverage vs wearability curve? Common sense says it would look like this:



2. What part of the body should the PFD cover to promote maximum wear rate?
3. What are the color, texture, pattern, image preferences of the various segments of the boating population?
4. What kind of closure mechanism is easiest to use in the water?

Wyle Wearability Studies — Nine hundred and ninety-five boats with 2448 people in those boats were observed and photographed from bridges at 16 locations around the country. PFD wear rates, accessibility, and type were recorded. Results showed that:

1. Wear rate is inversely proportional to boat length.
2. Cost of PFDs aboard is directly proportional to boat length.
3. Type II PFDs were seen most often in the boats, but Type III PFDs were worn most often (one exception, no. 6 below, see section 5.3).
4. Wear rate differed dramatically among locations.
5. Wear rate is relative to conditions.
6. Type II PFDs were worn more often than Type IIIs in a very hot environment.

The results seem to indicate that people who buy small, inexpensive boats also buy cheap PFDs. The least expensive PFD on the market is the Type II (AK-1). It is also the least wearable according to the study. Since drownings from accidents involving small boats account for a sizeable portion of recreational boating deaths, it seems obvious that sizeable benefit would be obtained if a cheap, wearable PFD were available.

The fact that Type II PFDs were worn most often at Lake Havasu on an extremely hot day supports the theory of minimum body coverage. The Type III vests may have been just too hot to wear that day.

In another wearability study, various types of PFDs were distributed to boaters who evaluated them, then wore them while boating, then evaluated them again. Results showed that appearance and image are the two most important factors in wearability.

Other Wearability Studies — Other PFD research efforts have yielded results that can apply to the design of advanced concept PFDs. Reports of these efforts are summarized below.

> Operations Research, Inc. (ORI) performed research on design criteria for advanced PFDs.[1] Their conclusions were in terms of performance criteria for wearability, physical effectiveness, and reliability. In terms of wearability, ORI researchers found that "no Coast Guard approved PFD exists that would

[1] Dayton, R.B., Design Criteria for Advanced PFDs, Operations Research, Inc., NTIS No. AD A010 404. 1974

be acceptable to the recreational boater for wearing at all times while afloat." They were too uncomfortable, hot, abrasive, bulky, and covered so much of the body that they prevented suntanning. Based on those conclusions, they recommended that advanced concepts design efforts be directed towards PFDs worn around the waist. They also recommended inflatable PFDs to eliminate weight and bulk.

Because ARM showed us that most fatalities occur within a few minutes after entering the water, accessibility tends to become the most important factor after wearability. The victim is safest with a PFD on, but apparently needs it most in the first few minutes. The wearable seat cushion concept seems to be quite valid as it may be grabbable while the victim is going overboard.

Wearability Studies - Conclusions — When the results of the two studies are combined, it appears that wearability rate may be increased in the future through the development of PFDs that:

1. are cheap
2. cover minimum skin area
3. are worn around the waist
4. are good looking
5. are backed up with a propaganda campaign that pushes "image".

In terms of answering the questions asked of the wearability studies, the body coverage versus wearability curve was verified in a way in both studies. Wear rate was inversely proportional to body coverage at Lake Havasu and interviewees did note a preference for PFDs having minimum body coverage.

The second question was answered in the ORI study.[1] Respondents noted a preference for PFDs worn around the waist. The answers to the third and fourth questions are important for the development of a PFD that will be worn more often. As shown in the results of one of the Wyle wearability studies, aesthetics and image were judged as being important factors in wearability. However, specific answers to the questions have not been formulated. More research is needed in those areas.

7.2.3 Inputs From Physical Effectiveness Studies to Alternate Concepts

The following questions were asked of the data on PFD physical effectiveness:

1. How much buoyancy (flotation in the right place) is really needed to save a significant number of lives?
2. Where should the center of buoyancy be?
3. Is there any indication that a device that is designed to be sat on and, therefore, more accessible might be more effective? or as effective?
4. What part of the body should the PFD cover to be most physically effective?

Results of Physical Effectiveness Studies — Unfortunately the answer to the first question doesn't exist in the data because all wearable PFDs used on recreational craft have the 15.5 pound fixed buoyancy requirement. Researchers have contemplated the effects of the minimum buoyancy, highly wearable devices and in fact built one for use in an alternate concept pilot study. With only 3.6 lb of buoyancy, the device kept the wearer's face out of the water (see Figure 7-6). Further research is planned to investigate the effectiveness of a PFD with minimum fixed buoyancy and an inflatable device incorporated into a wearable design.

Previous research shows that the center of buoyancy of a PFD must be located near the wearer's chin, several inches off his chest in order to be assured of turning unconscious wearers.[2,3,4] Any fixed buoyancy device which met these specifications would almost certainly be very low in wearability. The specifications, however, apply only to devices which are symmetrical about the wearer's left/right vertical centerline. A device which has an assymetrical center of buoyancy might require much less bulk to turn an unconscious wearer. This possibility will be considered in Phase II.

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[2] Arthur D. Little, Inc., Buoyancy and Stability Characteristics of the Human Body in Fresh Water, 1972. NTIS No. AD 708 188

[3] Dayton, R.B., Study of the Hydrostatic Moments of the Human Body and PFD, Operations Research, Inc., 1974.

[4] Underwriters Laboratories, Investigation of the Performance of Personal Flotation Devices, 1975. August CG-D-168-75. NTIS No. AD A017 101

7.2.4 Inputs From Reliability Studies to Alternate Concepts

The following questions were asked of the data on PFD reliability:

1. Where have the PFD failures been? (zippers, buckles, foam, enclosure)
2. What are the most reliable components?
3. What information do we have on inflatable PFD reliability?
4. What kind of closure mechanism is most reliable?

Results of Wyle Studies — Results of initial reliability studies have shown that fasteners fail more often than any other single component. Our of 32 recorded failures overall, 10 were due to fasteners: broken zippers accounted for eight failures and torn snaps and broken buckles accounted for two failures.

Wyle researchers intend to experiment with Velcro fasteners on various models of alternate concept PFDs. If Velcro will work satisfactorily under water, it may very well solve the fastener failure problem, as well as the size adjustment problem.

Velcro representatives state that their product is less effective under water. They recommend using their material in conjunction with a buckle or snap as a secondary fastener. Velcro engineering specifications have been ordered as it is not yet known whether the 50% decrease in holding power under water is in tensile or sheer or just what the breaking strength is.

The fact that the PFDs tend to lose buoyancy with age was alarming. Obviously, further study is needed to identify the reason for the loss in buoyancy.

Problems related to reliability have become evident as a result of using the inflatable Davy Belts in various tests. It seems that two belts were repacked with expended CO_2 cartridges in them. Because the cartridges and activating mechanisms are encased inside the inflatable bag, one cannot determine their condition merely by inspection.

The activating mechanism is on the outside of the inflatable bag on the "Compac" PFD from New Zealand. After actuation, the entire actuating mechanism must be disassembled before the actuating lever can be returned to its normal position. Nothing is foolproof. Someone

could disassemble the mechanism and reassemble it without installing a new CO_2 cartridge. However, the disassembly feature definitely seems to be an improvement over the Davy Belt configuration.

Care should be taken in the design of alternate concept inflatables to make sure that it is obvious when the CO_2 cartridge is discharged or when there is no CO_2 cartridge in the cartridge holder.

Wyle researchers have found leaks in the inflatable PFDs to be a problem. Various Davy Belts have been inflated for testing purposes about 18 times throughout the past year. Two have leaked. The leaks were isolated and were found to be from two sources; two pin holes in the fabric and a leak in the seal around the plug used to gain access to the CO_2 cartridge mechanism. Two failures were noted on the same PFD. Inspection of the holes indicated that they were opposite each other when the PFD was deflated. They were also on a fold in the fabric and could have been caused by a pinch, but were probably caused by a puncture from a sharp pin-like device. The holes were quite small so air leaked from the PFD at a very slow rate. Because the Davy Belt has no mechanism to provide oral topping up, its occupant would find himself in deep trouble if the PFD had to support him for any length of time.

Holes in the plastic coated fabric are inevitable. Because we have recorded only 18 usages and because they are being used in a research environment, a reliability estimate cannot yet be made for the recreational boating environment.

The seal on the access plug probably leaked because the plug wasn't fully tightened when the cartridge was replaced after the last use. The word "probably" is used because dirt could have gotten into the seat area and caused improper seating. However, this latter theory is improbable because inspection showed the area to be clean and free of all dust and dirt particles.

An investigation of the characteristics of the access plug showed that there is no seal such as an "O" ring or gasket. Instead, the inner surface of the plastic cap forms a seal against the top surface of the socket portion of the mechanism. There is no way to tell how tight to

tighten the cap. It leaked when finger tight, but required very little more torquing with a coin in the slotted cap to eliminate leaking. Some "feel" should be provided to indicate when the cap is tight enough. Better yet, eliminate the need for the access plug by locating the CO_2 cartridge on the outside of the inflatable bag as it is on the Compac.

Conclusions - Reliability — Results of initial reliability studies show that fasteners, especially zippers and buckles fail more often than any other single component. Wyle researchers intend to experiment with other fastener concepts including Velcro during the next phase of the program. Various PFDs will be refitted with the new fasteners and wearability, reliability, and physical effectiveness studies will be performed.

Some reliability information on inflatables was gathered by informal testing of two brands of inflatable PFDs. Conclusions were that the CO_2 bottle should be visible, the condition of the bottle (full, empty) should be obvious, and one should not have to open the bag to recharge the system.

Not enough data has been gathered as yet to rank order PFD components in terms of reliability. Reliability studies planned for the next phase of the program should provide that information.

7.3 FOREIGN PFD DESIGNS AND STANDARDS

When foreign PFD designs are discussed, the subject of inflatables and hybrid devices invariably surfaces. Because there are currently no provisions for Coast Guard approval of inflatable devices, American manufacturers have had no incentive to develop these types of PFDs. In fact, in a recent market search, few types of U. S. manufactured inflatables were found. One is used by scuba divers and another (inflatable suspenders) is used primarily by duck hunters. Since some foreign governments have adopted standards which permit the acceptance of hybrid or inflatable devices, the applicable regulatory agencies in seven foreign countries were queried as to:

1. the availability of design and/or performance standards for PFDs
2. the names and addresses of manufacturers of PFDs.

Letters were sent to:

Australia

Department of Transport, Coastal Services Div., Canberra City

Standards Association of Australia, Sydney

Canada

Equipment Inspection and Standards Division, Ottawa

Great Britain

Royal National Life Boat Institute, London

British Standards Institution, London

Japan

Japanese Maritime Safety Agency, Tokyo

Norway

Norwegian Classification Society, Oslo

Norwegian Maritime Directorate

Sweden

Sjöfartsverket, Stockholm

Replies with the requested standards were received from Australia and Canada. A reply but no standard was received from Norway. Great Britain, Japan, and Sweden did not answer the request.

7.3.1 Foreign Standards — Australian

Australia has three PFD standards controlled by three different agencies. The Marine Standards Division of the Department of Transport in Melbourne approves PFD's for use on Australian ships operating in the foreign and interstate trades. Such PFDs conform to specifications similar to the provisions of S.O.L.A.S., 1960.

Basically, the standard says that within five seconds after entering the water the PFD shall turn the wearer to a face up position so that his mouth is at least 4.5 inches (120 mm) above water. PFDs are divided into two size groups. The first is for people weighing over 70 lbs (31.7 kg) and provides 35 lbs (15.9 kg) of buoyancy. The second is for people weighing less than 70 lbs (31.7 kg) and provides 15 lbs (6.8 kg) of buoyancy.

The standard is basically for fixed buoyancy PFDs. A paragraph within the standard states that I.M.C.O. is presently revising standards for inflatables and that when the requirements are fixed, the Australian standards for inflatables will be re-issued. This can be interpreted to mean that Australia had standards for inflatables at one time. One authority of the Marine Standards Division wrote in a letter to Wyle, "At the present time, inflatable life-jackets are in the minority in Australia and this Department has not been asked to approve lifejackets of such type."

The second Australian PFD Standard is for use on fishing vessels engaged in intra-state trades. The marine authorities of each state approve PFDs used on such vessels to either the Australian Standard discussed above or to the "multifit" PFD specification which follows.

The "multifit" standard says that the PFD must turn the wearer, on entering still water, to a safe head-up floating position within six seconds. In that position, his mouth must be at least 3.9 inches (9.9 cm) above the water. Apparently, a PFD designed to conform to this standard should be capable of fitting anyone, regardless of his size. Red lights and whistles must be attached to the PFD's. It is unclear whether inflatables are permitted.

PFDs used on pleasure boats are approved by the Standards Association of Australia. Their standard AS-1512 covers the requirements for design, construction, and performance of fixed buoyancy PFDs intended for use in small boats in frequented or sheltered waters.

PFDs are divided into four types, according to the size of the wearer. The two smaller types are considered to be for children. The following table shows the classifications.

Size of Wearer	Buoyancy of PFD	
Persons over 40 kg (88 lbs)	87 N	(20 lbs)
Persons between 22 kg and 40 kg (48 to 88 lbs)	49 N	(11 lbs)
Persons between 11 kg and 22 kg (24 to 48 lbs)	40 N	(9 lbs)
Persons under 11 kg (24 lbs)	31 N	(7 lbs)

The adult PFDs are required to turn the wearer to a face-up position within 10 seconds and maintain him in that position with his nose and mouth well clear of the water. The specification for the childrens PFDs substitute the word "immediately" for "ten seconds".

Provisions are made in the standard for fixed buoyancy and inflatable PFDs. The inflatables can be manually or automatically inflated using CO_2 only. All must have a valve for oral "topping up". The Quality Assurance and Certification manager of the Standards Association of Australia wrote in a letter to Wyle, "Boating Regulations operative in Australia require lifejackets to be worn by occupants of pleasure craft." This can be interpreted to mean that boaters have to wear PFDs all the time while boating. Further correspondence has been initiated to clarify the statement and subsequent assumption.

7.3.2 Foreign Standards — Canadian

Canadian PFD standard 65-GP-11 was obtained from the Canadian Department of Transport, Marine Division. In a letter from the Department of Transport to Wyle, the Superintendant of Equipment and Cargoes stated that they will approve inflatable devices; however, no such device has been submitted for approval. In fact 65-GP-11 applies to PFD's of two different types:

Type I — Fixed Buoyancy (15.5 lbs, 7.05 kg)
Type II — Combined buoyancy (9 lbs, 4.1 kg fixed plus 20 lbs, 9.1 kg inflatable)

The standard requires that all PFDs whether inflated or deflated must provide flotation without tending to turn the wearer's face into the water. Type I PFDs and type II PFDs when inflated must hold the wearer's face up and clear of the water. Type II PFDs when inflated must turn the body over to a face up position within 10 seconds.

The inflatable mechanism must be a manually operated CO_2 device actuated by a load not exceeding 15 lb (6.82 kg) and fully inflating the device in less than five seconds.

It is interesting to note that the Canadian Government requires the following comment to be printed on each wearable PFD in both English and French:

THIS PFD IS DESIGNED TO BE WORN
WEAR IT!

7.3.3 Foreign Standards — Norway

The Norwegian Maritime Directorate approves PFDs for use in that country. Correspondence with them indicated that they have not approved any type of inflatable PFD. However, research is presently underway to create a specification for inflatable PFDs.

In addition to contacting foreign regulatory agencies, letters were sent to manufacturers of PFDs, to obtain brochures and prices. Based on the literature received from foreign PFD manufacturers, two each of thirteen different models were ordered through Coast Guard Headquarters. As yet none have been received. Specifically, those PFDs on order are:

Beaufort Equipment Limited
Beaufort Road
Birkenhead, England

1) Failsafe Sportsfoam Mark 5N
2) Sportsman Mark 5N
3) Supermariner Mark 5N
4) Failsafe Bambino Mark 5N
5) E.L.J. Mark 10N

Alsafe Industries Pty. Ltd
Vic.: Melbourne, Australia

1) Multifit - ALJ1
2) Tadpole - ALJ27

Secumar
Bernhardt Apparatebau
G.m.b.H.u. Co.
2 Wedel/Holst
ABC-Strasse 16
West Germany

1) Secumar 11m
2) BS 8 Secumatic (with extra tablets and gas cylinders - 12 each)
3) Secumar 9S
4) 16KK Secumatic (with extra tablets and gas cylinders - 12 each)
5) Secumar 17

Davy Products International
Middlesex, England

1) Safari Jacket

Table 7-1 lists ten of the hybrid and inflatable PFDs available on the foreign market and compares some of their features. Of the ten evaluated, the Davy Belt, the Beaufort ELJ

TABLE 7-1. ALTERNATE PFD CONCEPTS — FOREIGN

Type & Model	Manufacturer And Location	Advertised Buoyancy		Features	Comments
Inflatable Belt DVB	Davy Belt London, England	None: Tested By Wyle to 18 lbs		Very Wearable Lightweight Decorative Belt	Uses CO_2 Bottle with Manual Actuator
Hybrid Yoke Sportsfoam Mark 5 N	Beaufort London, England	Deflated 13-1/2 lbs	Inflated 35 lbs	Foam With Air Inflation (Manual)	Added Hyperthermia Protection
Inflatable Yoke	Beaufort London, England	0	35 lbs	Air Inflated Folded Yoke (Manual)	No Inherent Buoyancy
Inflatable Yoke Super Mariner Mark 5N	Beaufort London, England	0	35 lbs	Gas Filled Manual Actuator	No Inherent Buoyancy
Yoke Gas/Air Inflatable Mark 10N	Beaufort London, England	0	35 lbs	Gas/Air Inflation	Flat Fold Very Comfortable
Yoke Failsafe Bambino Mark 3N	Beaufort London, England	10 lbs	20 lbs	Foam/Air	Closed Cell Foam - Redundancy
Secumar 17 Yoke	Secumar Hamburg, Germany	Conforms to Solas Convention Estimated 30 lbs		Excellent Faceup Features	Made of Closed Cell PVC. Very Bulky
Secumar 12K Inflatable Yoke	Secumar Hamburg, Germany	Estimated - 14 lbs		Lightweight Fully Automatic CO_2 Inflation	Available in Automatic Actuator or Manual Lifting Strap and Life Line Options
Inflatable BS8 Yoke	Secumar Hamburg, Germany	Estimated - 15 lbs		Fully Automatic Flat, Fits Well and is comfortable Manual inflation capacity is available	Good for fishermen Single Chamber is a disadvantage has many applications for
Inflatable Jacket SCU-20	St. Cloud Minn. U.S.A.	Estimated 14 lbs		Inflatable by CO_2 or Air	Suitable for Scuba Divers Only

Mark 10N and the Secumar 12 KL Secumatic are of most interest. These PFDs can be inflated orally or by manually rupturing a CO_2 bottle with a built-in actuator. The Secumar 12KL Secumatic has three methods of actuation, orally, manual firing of CO_2 bottle, and automatic firing upon entry to water. The Secumar 12KL Secumatic as shown in Figure 7-1 utilizes a disolvable pill to release the spring loaded firing pin which ruptures the CO_2 bottle. The triple redundancy built into this configuration increases reliability. The addition of another CO_2 system and isolation compartments with internal check valves would further improve reliability.

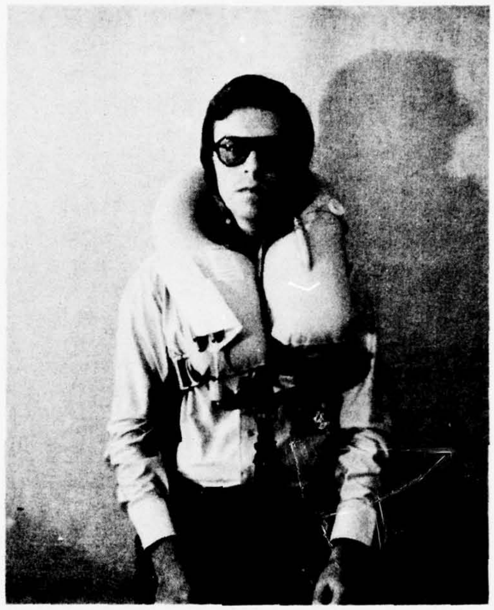


FIGURE 7-1. SECUMAR 12 KL SECUMATIC

The Davy Belt, an inflatable belt type PFD manufactured in Great Britain has undergone preliminary tests by Wyle. The results of these tests are discussed in Section 7.4.1 of this report and also in the Reliability section. The wearability of the Davy Belt is excellent and the overall reliability can be improved with simple modifications to the actuator. Wyle has been informed by "The Mail Boat, Inc.", U.S.A. distributors of the Davy Belt, that it is approved for use in Sweden and Japan; however, this is unconfirmed. The Davy Belt is discussed in more detail in Section 5.4.2.

Two Australian hybrid PFDs manufactured by Beaufort of London, England are of interest. These two were the Beaufort Mark 5N and the Mark 3N, yoke type, both of which utilize closed cell foam and air. No provision for gas inflation exists for these PFDs and they must be orally inflated. One possible configuration would incorporate the features of the Secumar 12KL Secumatic (oral, manual, and automatic inflation), as well as fixed buoyancy. The Beaufort devices are approved in Great Britain under standard BSS 35951.69.

Hybrids and inflatables show promise for the future; however, much research and evaluation is needed before such candidate PFDs could undergo serious consideration.

7.4 ALTERNATE CONCEPT DEVELOPMENT

7.4.1 Tests Of Hybrid Devices

As noted in the previous section, foreign countries are using combined fixed buoyancy and gas or air in hybrid PFD configurations. This configuration should be acceptably reliable.

Wyle tested three types of hybrid devices, each with a different amount of fixed buoyancy and inflated buoyancy. Specifications of the three experimental devices are shown in Table 7-2.

TABLE 7-2. BUOYANCIES OF THREE EXPERIMENTAL PFDS

Configuration	Fixed Buoyancy	Inflated Buoyancy (Fixed plus inflated buoyancy)
A	15 lbs (6.8 kg)	33 lbs (15.0 kg)
B	7 lbs (3.17 kg)	20.4 lbs (9.3 kg)
C	3.6 lbs (1.6 kg)	17 lbs (7.71 kg)

Above buoyancies were measured using the Wyle designed Buoyancy Test Fixture in fresh water at 75 degrees (F) (22 degrees C).

Vest with Inflatable Belt (Configuration "A") — The first "hybrid" PFD tested consisted of a ladies small Sans-Souci Type III PFD manufactured by Stearns. This was a typical Type III vest available commercially almost everywhere. The inflatable portion of the "hybrid" device was a Davy Belt manufactured by S.O.S. Swim Wear Ltd. in England. The device appears to be a nautically styled belt; however, inside the device is an uninflated tube that can be inflated manually by squeezing a handle that punctures a CO_2 cartridge within the tube. As the tube inflates, it forces velcro fasteners in the belt covering to open. The tube then floats up and supports the wearer under the armpits.

The test was divided into three parts; one using the vest alone, one with the Davy Belt alone, and one with the combination of the two. Each time the subject was asked to don the device, enter the water and float in two positions: a) with legs extended forward and head back, and b) with legs down and head erect. The subject was not asked to float face down; therefore, it is unknown if this configuration would have turned the wearer to a face up position.

Results are expressed as the vertical distance from the mouth to the waterline and are presented in Table 7-3 for all three configurations in the first test. Results for the hybrid and each component are also shown in Figures 7-3, 7-4, and 7-5.

TABLE 7-3. DISTANCE OF MOUTH ABOVE WATER - CONFIGURATION A

Configuration	Head Back Legs Forward	Head Erect Legs Down
Vest Alone	4.5 in. (11.4 cm)	6.4 in. (16.3 cm)
Davy Belt Alone	6.8 in. (17.3 cm)	7.8 in. (19.8 cm)
Combination	7.8 in. (19.8 cm)	10.9 in. (27.7 cm)

TABLE 7-4. DISTANCE OF MOUTH ABOVE WATER - CONFIGURATION B

Configuration	Head Back, Legs Forward	Head Forward Legs Back
Ski belt	3.7 in. (9.4 cm)	immersed
Ski belt plus inflatable	3.5 in. (8.9 cm)	immersed

TABLE 7-5. DISTANCE OF MOUTH ABOVE WATER - CONFIGURATION C

Configuration	Head Back Legs Forward	Head Forward Legs Back
Fixed Flotation	1.3 in. (3.3 cm)	immersed
Fixed plus inflatable	1.5 in. (3.8 cm)	subject rolls over 1.5 in. (3.8 cm)

The subject was able to move freely while utilizing the hybrid configuration and no noticeable discomfort or fatigue was observed or reported.

Ski Belt With Inflatable (Configuration "B") — Researchers have held the concept that PFD wear rate and PFD body coverage may be inversely proportional. Previous wearability surveys have shown that a belt type PFD should have the highest wear rate.[1] People are used to feeling the constraints of a garment around the waist. Except for those wearing very brief bathing suits, a PFD worn on the waist would not reduce the skin area exposed to the sun for suntanning purposes.

Hybrid Configuration A consisted of a vest that totally covered the torso area. Since this doesn't meet the minimum coverage criteria discussed above, a second hybrid was developed and consisted of a ski-belt with an inflatable football shaped PFD attached to the front of it. (See Figures 7-6 through 7-9).

The expected advantages of this configuration are:

1. The ski belt would be more wearable than the vest.
2. In most instances, the ski belt would be used alone; however, the inflatable portion could be used when needed.
3. The two together would give more buoyancy than a Type II PFD; however, they probably wouldn't hold an unconscious wearer's face above water.

The ski-belt was vinyl covered foam manufactured by Cypress Gardens, model 1255, medium. The inflatable was a "compac" model manufactured by Neill, Cropper and Company Ltd., Auckland, New Zealand.

The device was tested in two configurations; one using the buoyancy provided by the ski-belt alone, and the second using the combined buoyancy of the ski-belt and the inflatable device. In each configuration test, the subject was asked to enter the water, don the device, and float in two positions. Specifically, the subject took several deep breaths, exhaled, and went limp in the following positions:

1. Head back, legs forward
2. Head forward, legs back

Results are expressed as the vertical distance from the subject's mouth to the waterline and are presented in Table 7-4.

The subject then inflated the balloon like device on her stomach and assumed the same positions; i.e., head back/legs forward, and head forward/legs back. Results are expressed in terms of the vertical distance from the subject's mouth to the water and are as shown in Table 7-4 above.

Note that the hybrid PFD would not turn the subject over on her back in either of the configurations. This isn't surprising for the uninflated test even though the ski belt was turned so the buckle was in the back, giving the front more buoyancy. It was surprising, however, that the combination of the ski belt and the football like inflatable device mounted on the front wouldn't turn the subject over onto her back, probably because the center of buoyancy was not high enough. It was difficult for her to get from a vertical body position to the face down body position; however, once there and limp, the balloon on her stomach wouldn't turn her over. See Figure 7-9.

Inflatable Plus Minimum Fixed Buoyancy (Configuration "C") — The ski belt was still considered to be bulky even though it covered much less of the body than did the Type III vest tested above. Wyle researchers felt that a truly wearable device would have to cover even less body area than did the ski belt. In addition, it was felt that concentrating the buoyant material on the stomach of the subject would

1. Make the PFD more wearable when seated and leaning against a back rest.
2. Tend to turn the subject to a face up position in both inflated and uninflated conditions.
3. Appear less bulky.
4. Cover less skin area.

Five pounds was chosen as the minimum amount of fixed buoyancy permissible in an adult life preserver from a report written for the Coast Guard by ORI titled "Design Criteria for Advanced PFDs"[1], wherein they state, "An unconscious person requires about 15-20 lbs of buoyancy while a person who is conscious can reduce this need to about 5 lbs (2.3 Kg) through deep breathing."

A foam device was designed and constructed to fit behind and around the "compac" inflatable PFD. The initial goal was to provide five pounds (2.3 kg) of fixed flotation around the "compac" in such a way that it did not increase the visual or functional bulk of the "compac." The test device was made of closed cell foam from a ski vest. Pieces were cemented together to form the approximate shape of a molded foam structure.

The device was tested in the same manner as the ski-belt/compac combinations was tested. The subject was asked to enter the water, don the PFD, and go limp in two positions. She did this first with the compac uninflated, then with it inflated.

Results showed that the fixed flotation portion of the PFD did not have enough buoyancy to float the subject when she expelled the air from her lungs. Buoyancy tests of the device later showed that there was actually only 3.6 pounds (1.6 kg) of buoyancy in the foam structure.

The "compac" was inflated and the subject again assumed the two positions. It was interesting to note that this configuration rolled her over on her back after she went limp with her face forward and down.

Table 7-5 , above, shows the vertical distance from the subject's mouth to the water in both configurations.

The minimum fixed flotation concept was successful in terms of wearability when the subject was out of the water. It did not hinder her movements when standing, walking, or sitting. However, the one inch wide strap (2.54 cm) that went around her back to secure the device against her waist tended to dig into her back when she was in the water with the "compac"

inflated. In fact, she was left with red strap marks on her back at the completion of the buoyancy portion of the experiment which lasted only about 10 minutes.

Unfortunately, we have one set of criteria that dictates minimum coverage that is opposed to the problem that dictates a wider belt to spread the upward pull of the PFD over more body surface area.

Advanced Concept Comparison — The measured parameters of the three advanced concept PFDs are tabulated in Table 7-6. Because the vest/Davy Belt combination was actually donned as two separate PFDs, donnability comparisons weren't made. If the concept were put into production, the two would obviously be combined into one PFD. In that case, it is reasonable to expect that donning times for the vest/inflatable would be no longer than for the ski-belt/inflatable combination.

If we compare the wearability portion of the table, we find that the minimum coverage device was most wearable out of water but least wearable in water because the strap cut into the subject's back. Both prototype configurations (B and C) were considered "ugly." The vest was considered as being not attractive but not objectionable in appearance either. These conclusions are reasonable to expect, since vests are the most attractive of currently available PFDs and the prototypes were quite rough in appearance.

In terms of keeping one's head out of water, the vest/Davy Belt combination was clearly the most effective, mainly because it had 33 lbs of buoyancy. However, it is interesting to note that the inflated "minimum fixed flotation belt" with half of the buoyancy of the vest/inflated Davy Belt combination also turned the subject over to a face-up position and kept the subject's face out of the water when she was in the huddled position (see Figure 7-13).

With both the ski-belt inflatable and the minimum buoyancy inflatable, the addition of the inflatable portion of the PFD did not increase the distance of the subject's mouth from the water. However, it did lift her torso considerably. See Figures 7-8 and 7-12.

Configuration						Wearability			
Type of Fixed Flotation	Pounds of Buoyancy	Inflatable Flotation	Inflated?	Pounds of Buoyancy	Total Buoyancy	How Easy to don 1 = Difficult 4 = Easy	Standing Comfort 1 = Uncomfortable 4 = Very comfortable	Sitting Comfort 1 = Uncomfortable 4 = Very comfortable	Freedom of movement 1 = uncomfortable 4 = very comfortable
A. Type III Vest	15	Davy Belt	No	0	15	N/A	2	2	2
Type III Vest	15	Davy Belt	Yes	18	33	N/A	N/A	N/A	N/A
B. Ski-belt	7	Compac	No	0	7	2	2	2	3
Ski-belt	7	Compac	Yes	13.4	20.4	2	2	2	3
C. Minimum Fixed Flotation	3.6	Compac	No	0	3.6	3	3	3	3
Minimum Fixed Flotation	3.6	Compac	Yes	13.4	17	3	3	3	3

TABLE 7-6. ALTERNATE CONCEPT CONFIGURATION COMPARISONS

Wearability					Physical Effectiveness					
... 4 = Very comfortable	Sitting Comfort 1 = Uncomfortable 4 = Very comfortable	Freedom of movement 1 = uncomfortable 4 = very comfortable	Attractiveness 1 = Ugly 4 = Attractive	Donability 1 = Very difficult 4 = Easy	Time to Don In Water	Swimability 1 = Serious hindrance 4 = Helps swimming	Turns subject Face up	Holds head above water in huddled pos.	Distance from mouth to water - head back pos.	Comments
2	2	2	3	N/A	N/A	4	No	No	4.5	2 separate PFD's — time to don wasn't recorded.
/A	N/A	N/A	N/A	N/A	N/A	3	Yes	Yes	7.8	Wearability parameters not measured with Davey Belt inflated.
2	2	3	1	2.5	40	4	No	No	3.7	Holds head out while fastening.
2	2	3	1	N/A	N/A	4	No	No	3.5	
3	3	3	1	2.5	37	3	No	No	1.3	
3	3	3	1	N/A	N/A	3	Yes	Yes	1.5	Strap cut into subject's back, rolled her over quickly onto her back.

7.4.2 Conclusions And Recommendations

Based on the results of the experiments, the following conclusions were made:

1. A minimum fixed flotation/inflatable combination belt type PFD can be both wearable and highly physically effective.

2. An improved minimum fixed flotation/inflatable hybrid should be developed as part of the 1977 PFD research project. Improvements should include:

   - wider strap
   - aesthetic improvements
   - easier to don and fasten
   - less bulk forward
   - five lbs (2.3 kg) fixed flotation
   - possible changes in inflated flotation size and shape

3. The minimum fixed flotation/inflatable device should be compared to the 13 inflatable foreign PFDs ordered for study during the 1977 PFD research effort.

Researchers believe that the donning time for minimum coverage PFDs can be significantly reduced through efficient closure design and placement. The ski belt and minimum flotation belt had awkward closure devices located on the subject's back. This was considered acceptable because both devices were strictly prototypes for preliminary research.

A center-front closure is probably the easiest to use, because people are used to fastening articles of clothing directly down the middle of their torsos. A problem develops when one considers placing the inflatable flotation device and the closure at the same location. Either the closure can be located front-center or the inflatable bag can ... not both.

The female subject used in the above experiments rated the minimum flotation device as being very ugly. In fact, it protruded from her stomach and gave her somewhat of a "pregnant profile."

Wyle has devised a way to move the closure to the front of the device and reduce the bulk of the profile by splitting the inflated buoyancy device into two smaller bags and locate each on the forward portion of the side of the belt. Both bags would be inflated by one actuator. Valves in each bag would maintain pressure in event of a leak in the other bag. An artist's concept of the improved minimum fixed flotation PFD appears in Figure 7-2.

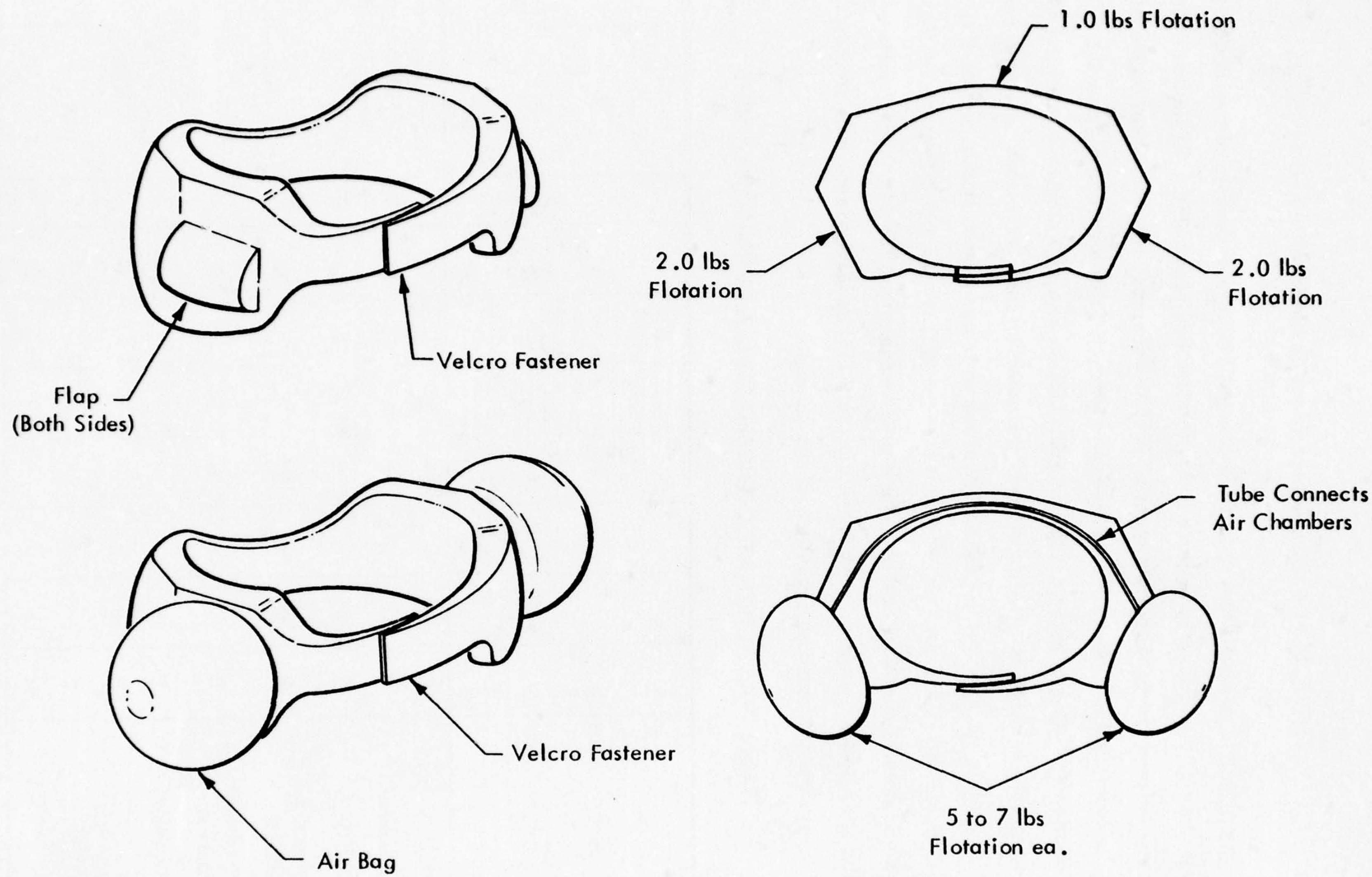


FIGURE 7-2. ADVANCED CONCEPT PFD

7.5 INTEGRATION - REQUIREMENTS WITH ALTERNATE PFD DESIGNS

Most of the alternate concepts that have been discussed involve inflatable or hybrid devices. Of course, it may be possible to improve fixed flotation devices as well. Earlier portions of this section defined several important areas of PFD functioning. To what extent do the alternate concepts discussed above incorporate improvements in at least one of these areas? Table 7-7 shows a listing of many of the important aspects of a PFD crossed with some PFD types. The table is meant to be illustrative of the potential benefits of some alternate concepts. A "0" in the table means that the PFD has about the same qualities in that aspect as currently approved Type I and II devices. A "+" means that the PFD type is probably better in that aspect than currently approved devices, while a "-" means it is probably worse. Some of these judgments are based on research (such as the alternate PFD concept experiments reported earlier), and some are based on the nature of the concept.

TABLE 7-7. ALTERNATE CONCEPTS VERSUS DESIRABLE FEATURES

	Current Types I, II	Current Type III	Current Type IV	Hybrid A Vest + Inflatable	Hybrid B Ski Belt + Inflatable	Hybrid C Min. F. B.	Wearable Seat Cushion	Inflatables	
Wearability	0	+	-	+	++	++	+	++	++ given to those PFDs that are worn around the waist.
Effectiveness	0	-	-	0	-	0	0	0	
Reliability	0	0	+	+[1]	0[2]	0[2]	0	0[2]	
Hypothermia Protection	0	+	-	+	-	-	0	-	
Sudden Drownings Protection	0	0	0	0	+	+	0	+	
Accessibility	0	+	+	+	+	+	+	+	
Image	0	+	0	+	?	?	?	?	
Aesthetics	0	+	+	+	?	?	?	?	
Cost	0	-	0	-	-	-	0	-	

Explanations of two of the entries in the table will serve to illustrate the way in which the table was completed. The entry footnoted "1" was made a "+" because the hybrid devices are at least as reliable as their fixed flotation components. Previous research has shown that currently approved devices often do not have 15-1/2 pounds buoyancy, while the Hybrid Vest in Table 7-1 has 13-1/2 pounds buoyancy. Thus, the inflatable part of the hybrid device can only increase reliability. Similarly, inflatables have been rated as equally reliable as currently approved devices (see footnote 2 in Table 7-7) for three reasons: 1) many currently approved devices are not reliable, 2) many foreign countries have approved inflatables, and 3) there are reliable actuation systems available and new "instant foams" which may prove to be adaptable to PFDs.

The belt type hybrid devices listed in the table are at the concept stage of development; therefore, no measure of aesthetics or image has been ventured. Experimentation is needed to determine the relative merits of each concept as compared to currently approved devices. The table is indicative of the kind of analysis that is needed. Through such efforts, it will be possible to determine which concepts have enough merit to warrant further development. Previous research has shown that throwables are not "holdable", Type IIs sometimes do not turn a relaxed victim, etc. Thus, there is room for the improvement of currently approved devices — in all aspects. Hybrids and inflatables show great promise since they tend to increase effectiveness and/or wear without sacrificing reliability. Their major problem seems to be cost. For that reason, the wearable cushion concept should be pursued as part of the 1977 PFD research effort. Every effort should be made to devise a cheap, wearable, good looking, throwable cushion that can be easily donned in the water.

7.6 RECOMMENDATIONS FOR FURTHER RESEARCH

The purpose of this section was to investigate the generality and applicability of the LSI to PFD design concepts which could not be approved under current standards, and to anticipated innovations in PFD design. Specific recommendations have been made within this section. One belt type hybrid device was recommended for further development as was the wearable cushion concept. In general, the criteria for advanced PFDs that have surfaced as a result of this research effort are:

1. PFDs must be cheap to be bought by owners of small boats (or provided as part of the "package" by the dealer).
2. The least expensive PFD available is also the least wearable.
3. Boaters prefer the belt-type PFD.
4. PFDs should cover the minimum amount of skin area.
5. A hybrid PFD can be both wearable and highly physically effective.
6. Donning time must be significantly reduced.
7. Fasteners fail most often on currently available PFDs.
8. CO_2 bottles on inflatable PFDs should be external to the inflatable bag.
9. Some means must be incorporated into the inflation mechanism of an inflatable to make it obvious that the CO_2 cartridge is either charged or spent.
10. One should never have to open the inflatable bag of an inflatable PFD.
11. Aesthetics and image are very important to wear rate.
12. Wear rate is inversely proportional to boat length.
13. Cost of PFDs aboard is proportional to boat length.
14. Type II PFDs were seen most often in boats but Type III PFDs were worn most often (one exception).
15. Wear rate is relative to conditions.

Based on the above results, Wyle recommends that research be carried on in two areas:

1. Inexpensive, wearable seat cushion.

   Goals include:

   - cost not to exceed that of typical Type II PFD
   - comfortable to sit on
   - comfortable to wear around the waist
   - good looking as a cushion and while worn
   - easy to don in the water
   - throwable

2. Small, waist worn hybrid PFD with minimum fixed flotation

   Goals include:

   - very comfortable to wear
   - good looking while worn
   - very easy to don
   - self adjusting for size
   - easy to tell if CO_2 cartridge is spent

If successful, the wearable seat cushion might have a higher overall life-saving capability than the AK-1s now on board many small boats. They would be more wearable, more accessible if not worn, and throwable. The waist worn hybrid would be very light, small, and attractive (for a PFD).

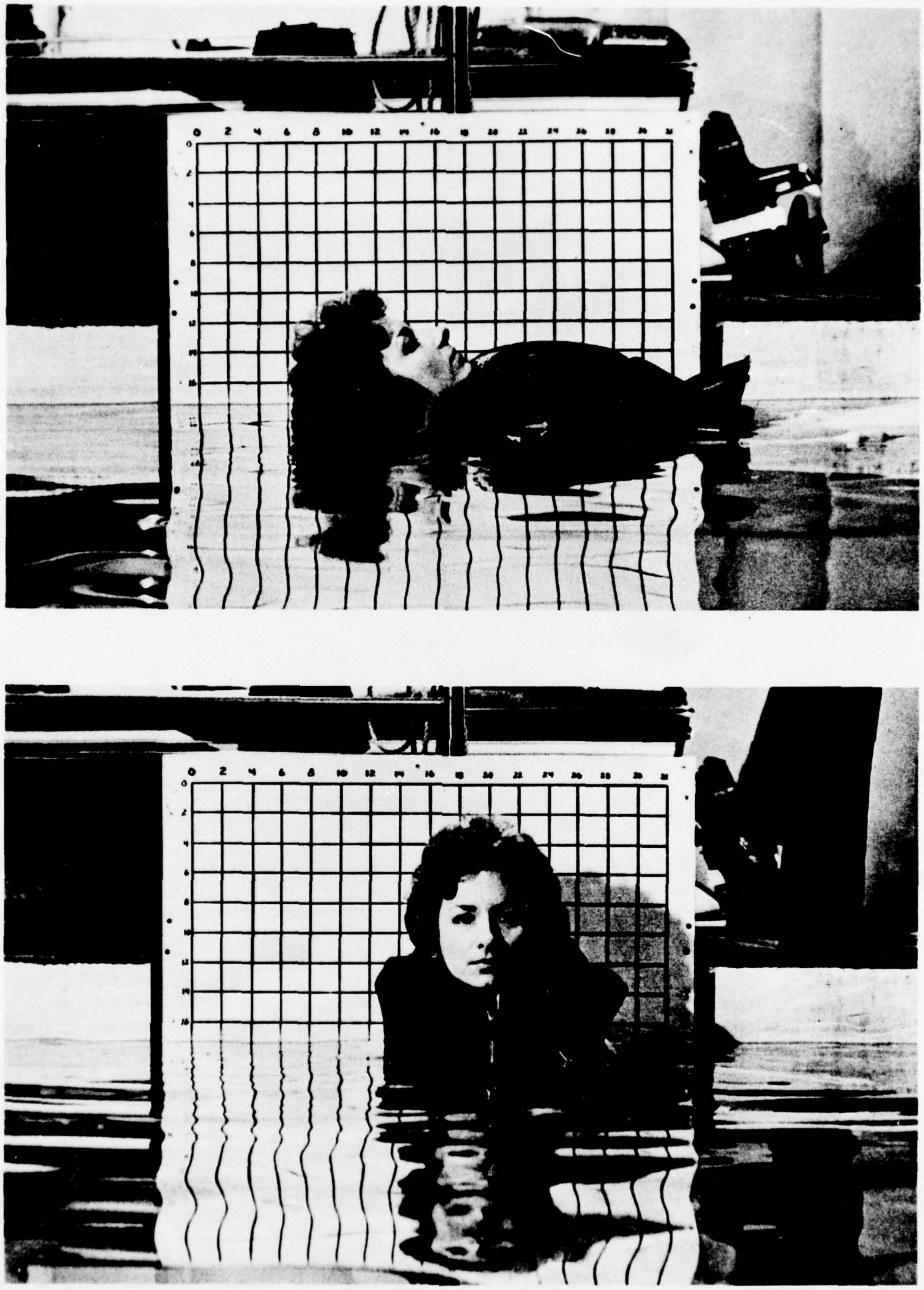


FIGURE 7-3. CONFIGURATION A - VEST ALONE - INFLATABLE NOT INFLATED

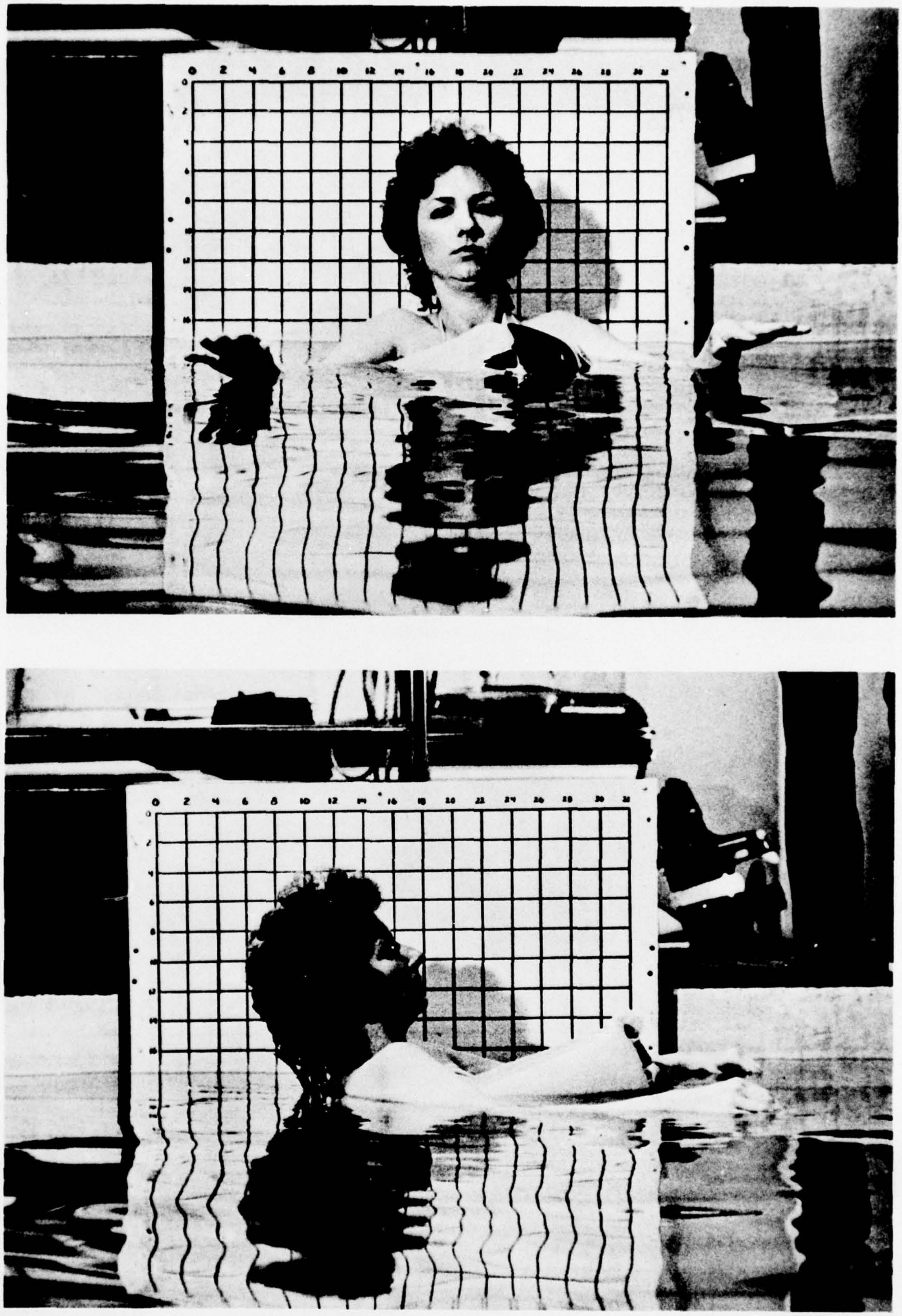


FIGURE 7-4. CONFIGURATION A - DAVY BELT ALONE - VEST NOT WORN

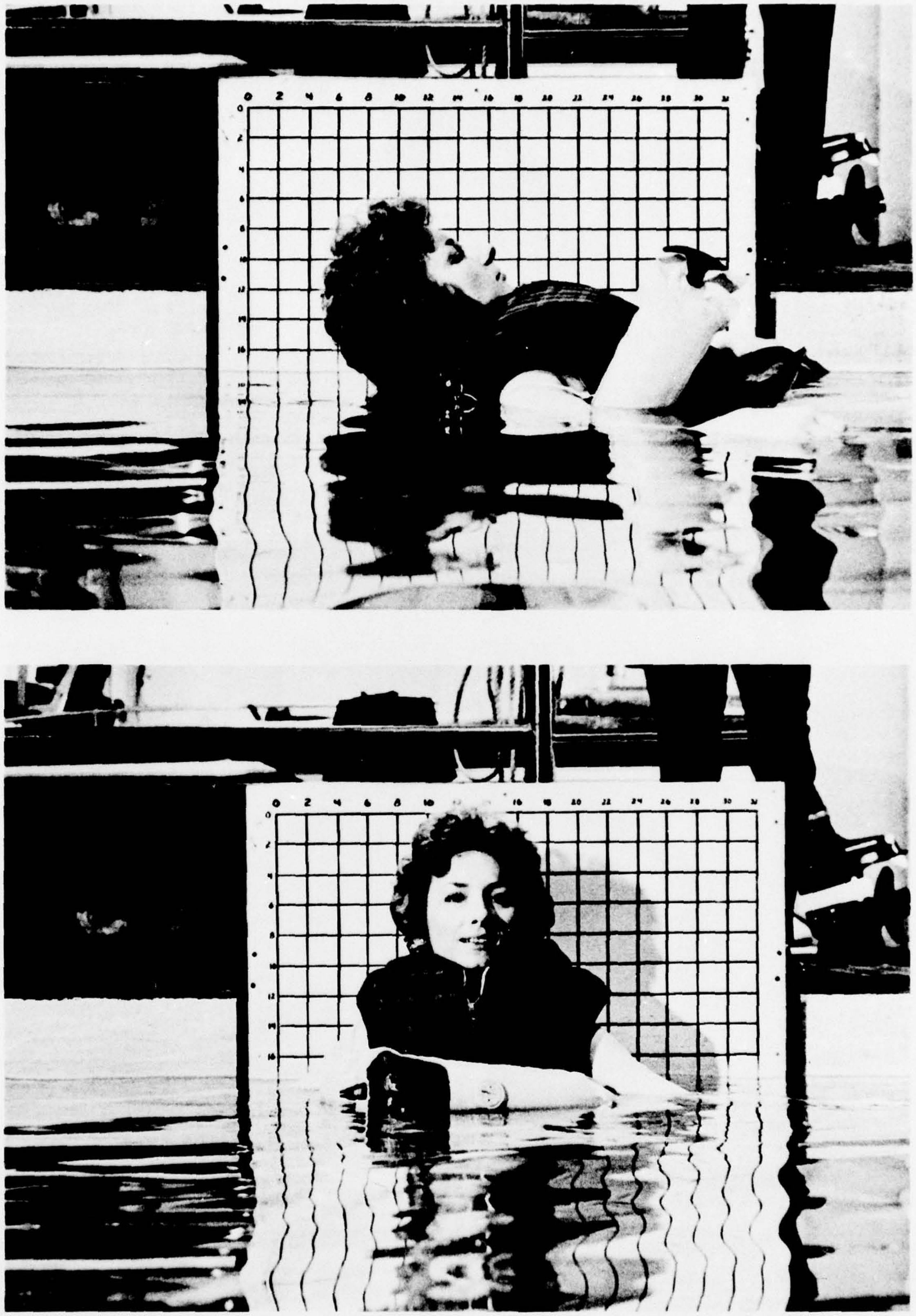


FIGURE 7-5. CONFIGURATION A - VEST AND INFLATABLE DAVY BELT

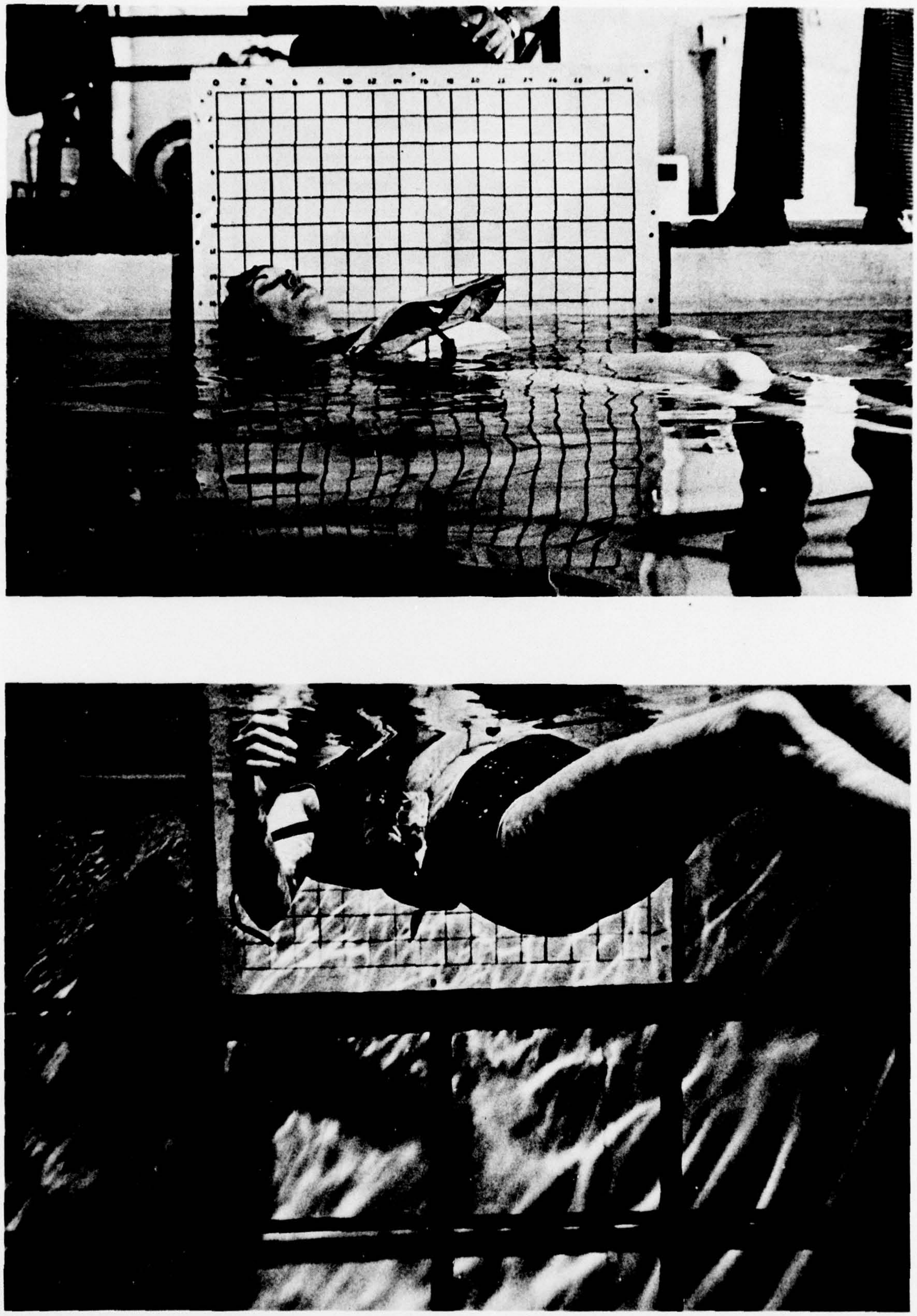


FIGURE 7-6. CONFIGURATION B - SKI BELT - INFLATABLE NOT INFLATED - SUBJECT IN EQUILIBRIUM

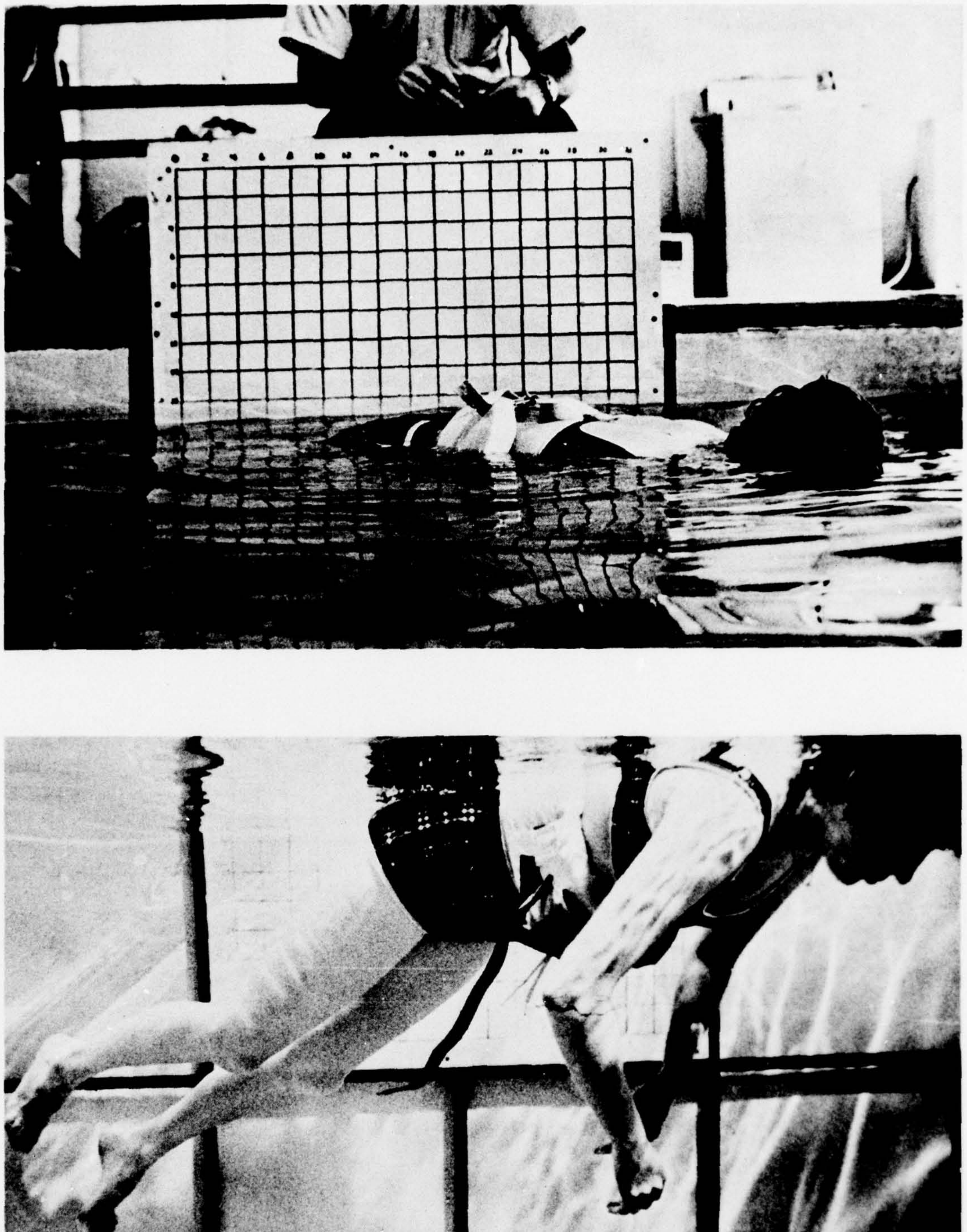


FIGURE 7-7. CONFIGURATION B - SKI BELT - INFLATABLE NOT INFLATED - SUBJECT IN EQUILIBRIUM

FIGURE 7-8. CONFIGURATION B - SKI BELT - INFLATABLE INFLATED - SUBJECT IN EQUILIBRIUM

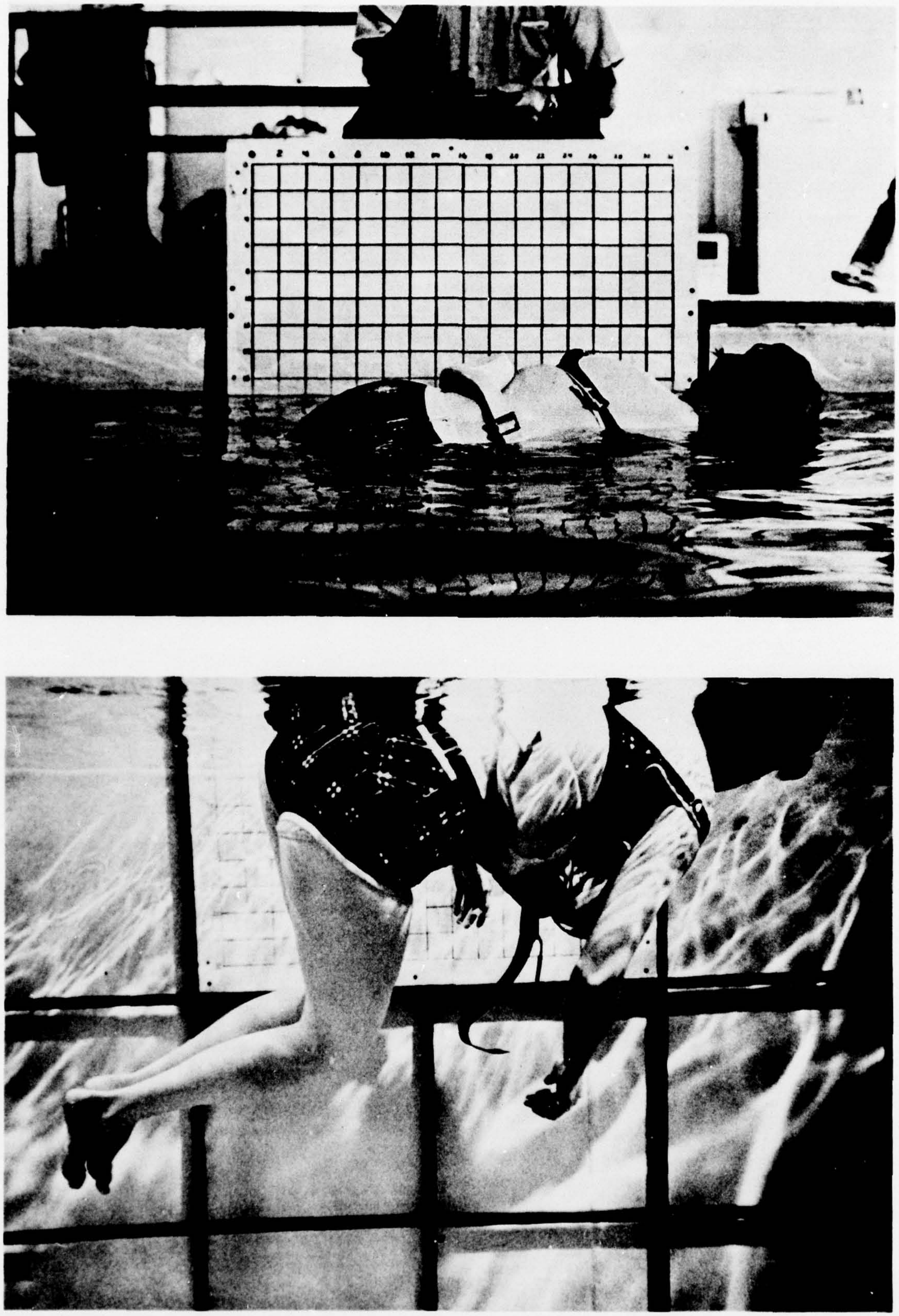


FIGURE 7-9. CONFIGURATION B - SKI BELT - INFLATABLE INFLATED - SUBJECT IN EQUILIBRIUM

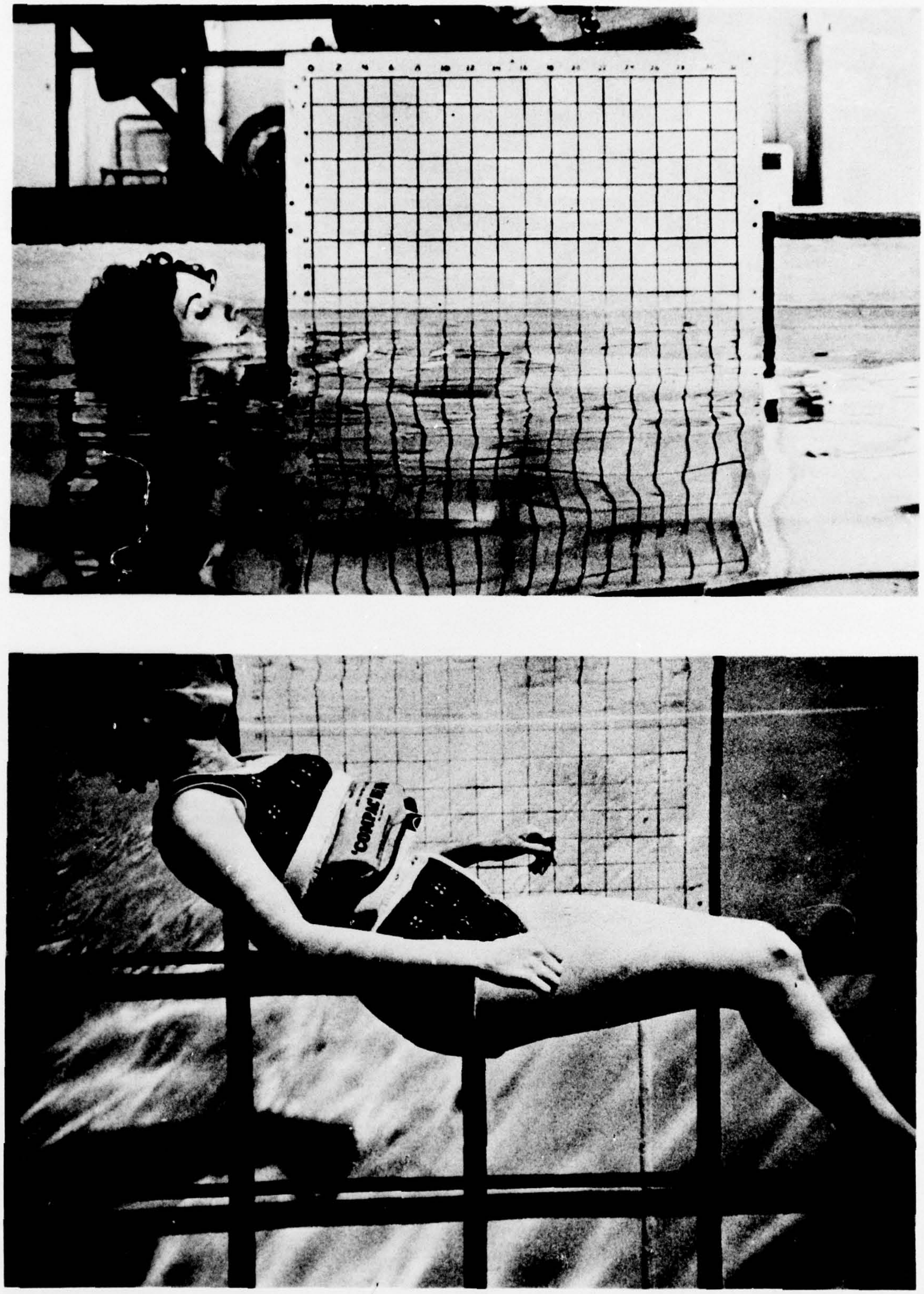


FIGURE 7-10. CONFIGURATION C - MINIMUM FIXED BUOYANCY - INFLATABLE NOT INFLATED - SUBJECT IN EQUILIBRIUM

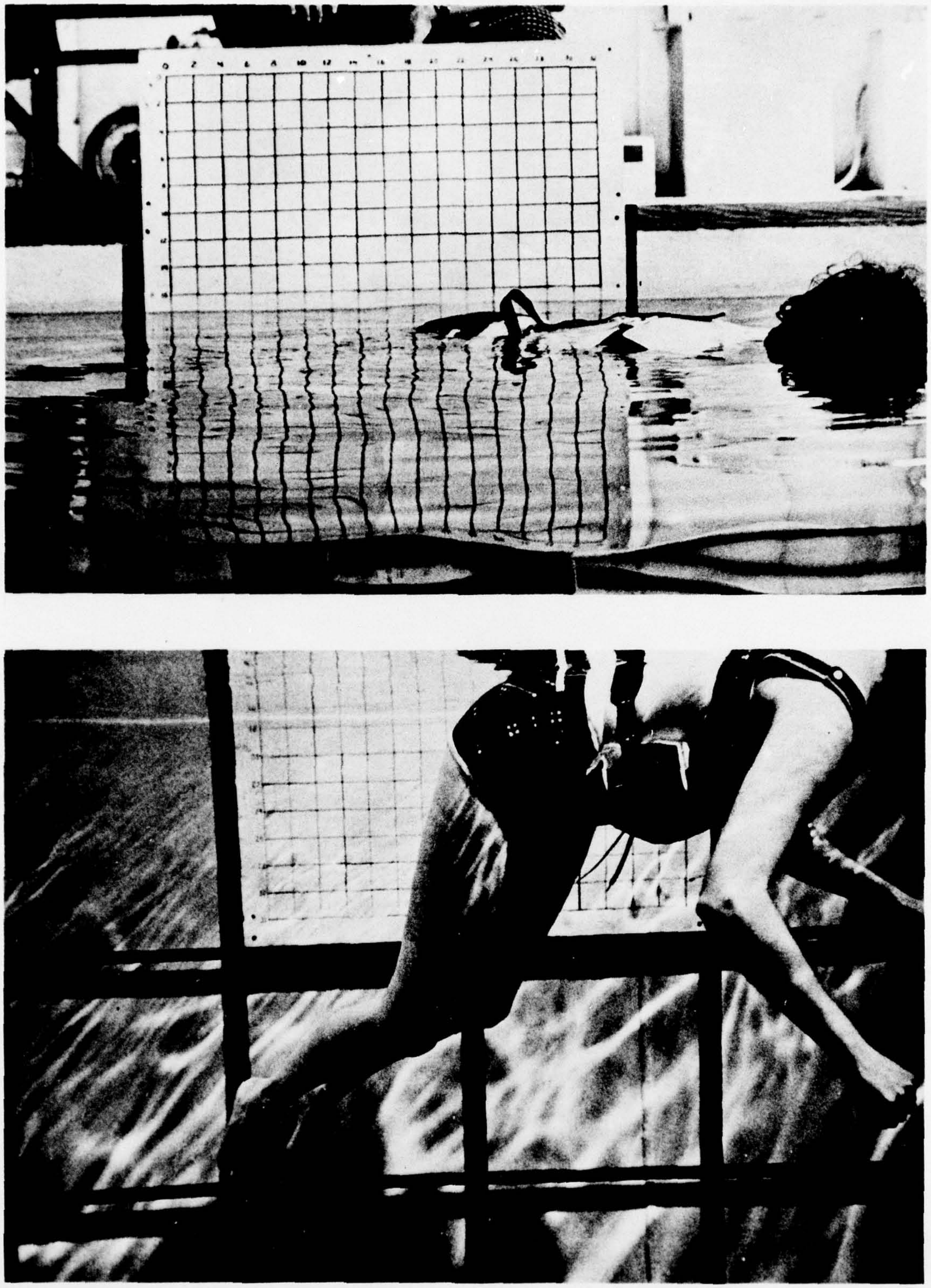
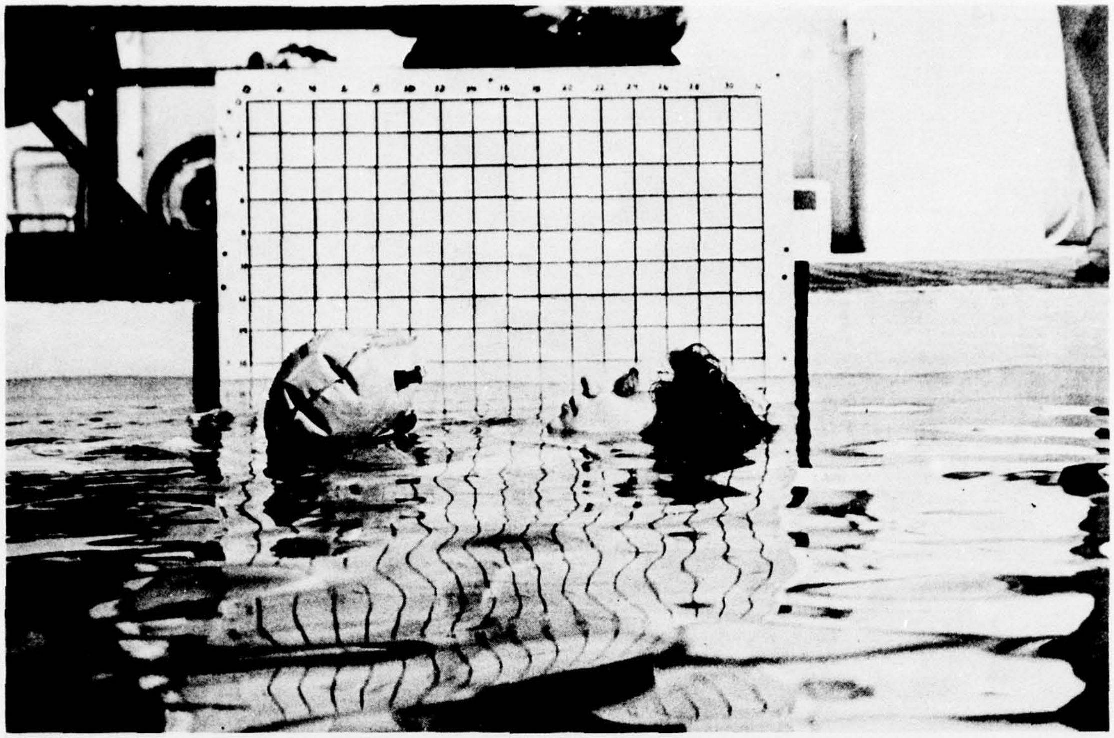


FIGURE 7-11. CONFIGURATION C - MINIMUM FIXED BUOYANCY - INFLATABLE NOT INFLATED - SUBJECT IN EQUILIBRIUM



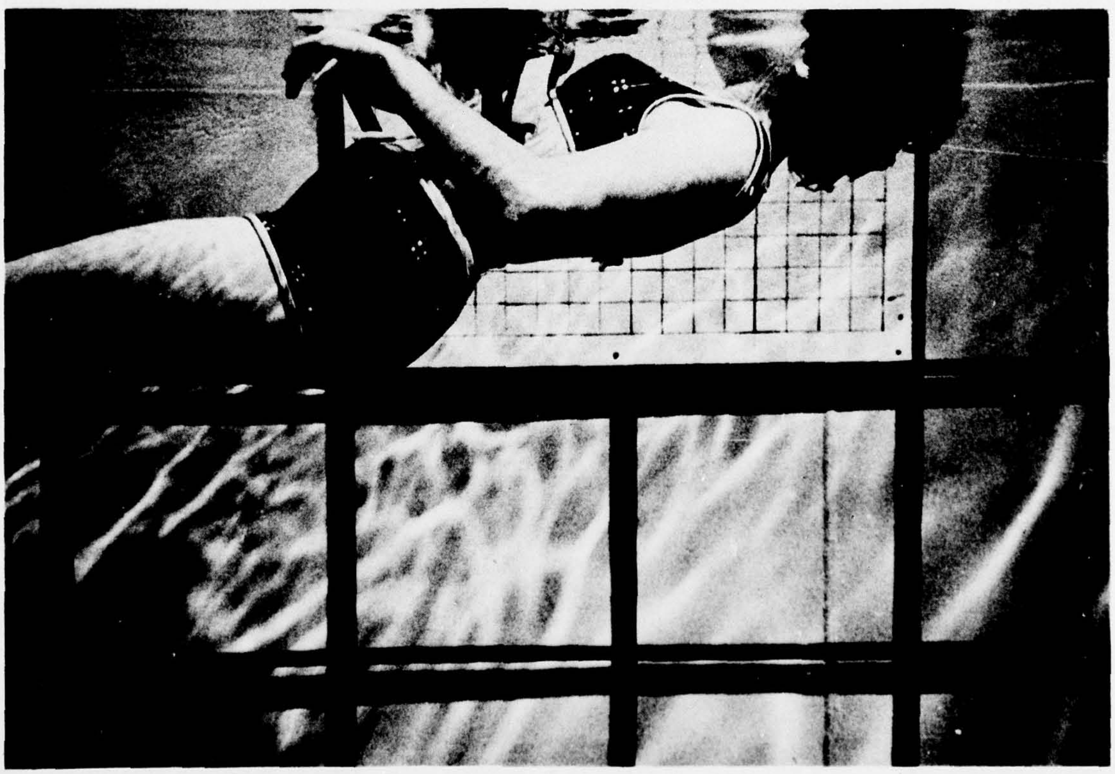


FIGURE 7-12. CONFIGURATION C - MINIMUM FIXED BUOYANCY - INFLATABLE INFLATED - SUBJECT IN EQUILIBRIUM

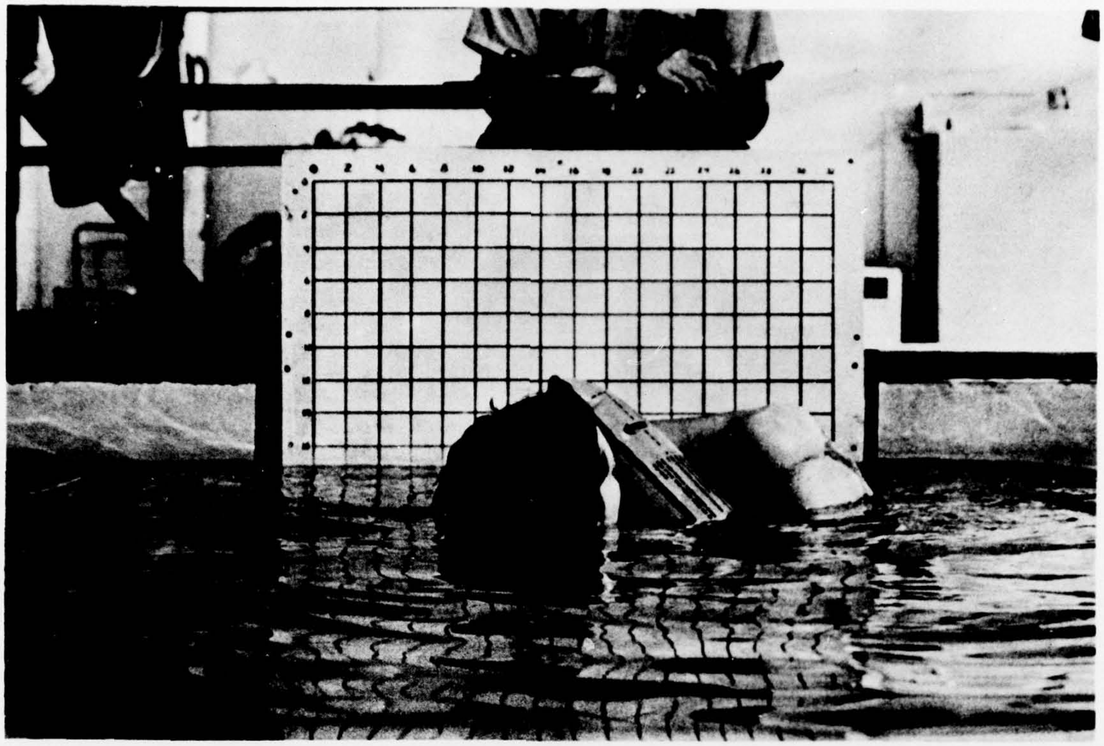


FIGURE 7-13. CONFIGURATION C - MINIMUM FIXED BUOYANCY - INFLATABLE INFLATED - HUDDLED POSITION